# COMBUSTION

JA 24 1938

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 9, No. 7 JANUARY, 1938 25c a copy

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New boiler house of RCA, Camden, N. J., employing high steam pressure

## Utility Plant Supplying Steam to Packing Houses

## Tests on Draft Fans for Logan Steam Plant

## Combustion of Pulverized Coal

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# COMBUSTION ENGINEERING

# COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME NINE NUMBER SEVEN

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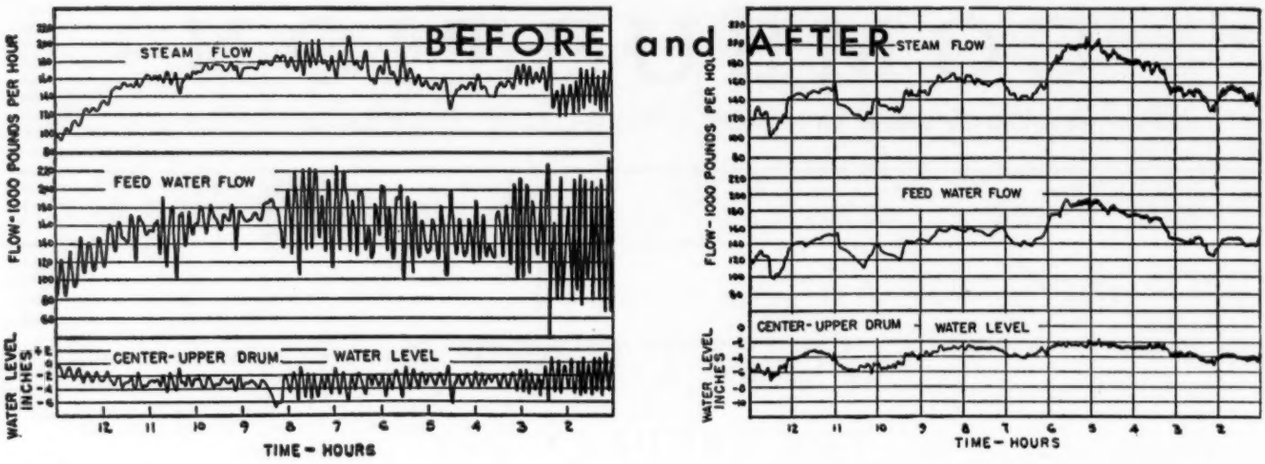


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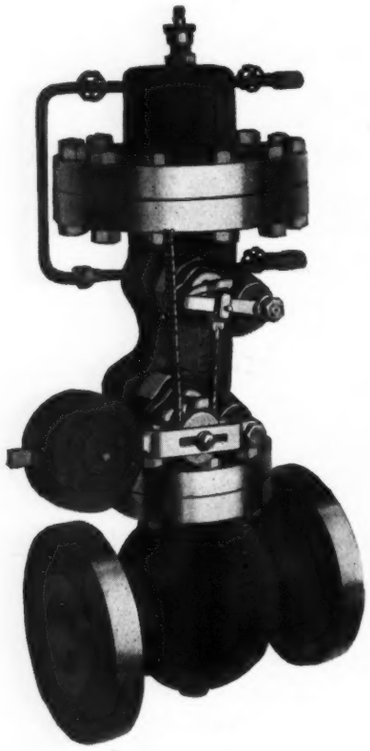

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# EDITORIAL

## Intrastate Coal Falls under Bituminous Code

Basing its action on Section 4 of the Bituminous Coal Act of 1937, which gives the Bituminous Coal Commission authority to determine the effect of intrastate transactions on interstate commerce in bituminous coal, particularly where the two may be in competition, the Commission has lately ruled that all such coal mined in the States of Ohio, Iowa, Kentucky, Illinois, Maryland and Indiana is subject to its jurisdiction and to the Coal Code, whether intended for use within or without those States. It is likely that similar action will be taken with regard to other bituminous coal-producing States.

This is one of the most important decisions yet reached by the Commission. It undoubtedly simplifies the problem of regulation and lessens what otherwise might result in attempts to avoid full compliance with the Act, for a commodity such as coal would be most difficult to follow from source to point of utilization. However, this interpretation of the Act serves as one more illustration of how Federal authority can circumvent what was formerly regarded as strictly States Rights. By placing such a broad construction on intrastate commerce as competitive with that embracing interstate transactions, it is conceivable that the reasoning might be applied to practically all commodities.

## Effect of Water Walls on Combustion

In the early 'twenties when pulverized coal firing and water-cooled furnaces were beginning to be applied in a big way, opinion was divided as to whether bare water walls would retard combustion, particularly during the starting-up period or at low ratings. The subject was widely discussed and some may recall that Professor Christie, at the time, answered these sceptics by pointing out that the well-known Scotch marine boiler had long employed a completely water-cooled furnace without any detrimental effects. Since then water-cooled walls and the development of pulverized coal firing have gone hand-in-hand and have made possible the large steam-generating units and high combustion rates of today.

Despite this, one occasionally notes a disposition to attribute certain combustion difficulties to the cooling effect of water walls. Those who entertain such a belief would do well to read carefully the dissertation by Henry Kreisinger on "Combustion of Pulverized Coal," in this issue. By tracing just what goes on in the furnace, the author shows that proper mixing through turbulence, rather than temperature, is the key to good combustion; and that difficulties at low ratings are usually traceable to improper air supply, velocity or distribution. Furthermore, experiments by the Bureau of Mines are cited to show that excessively high temperatures are not only unnecessary for rapid combustion, but beyond a certain point actually retard the speed of combustion. In fact, if the furnace temperature is too high, when burning a coal of low fusing ash, molten ash may accumulate on the boiler tubes at high ratings.

Coincident with the presentation of Dr. Kreisinger's paper at Detroit, was a paper delivered by R. F. Davis, a well-known British engineer, before the Institution of Mechanical Engineers (London) on November 19, 1937, in which he gives the following conclusion:

"Once ignition has commenced there is a definite advantage, apart from the question of ash fusion, in maintaining the flame temperature as low as possible; it is evident from the equations that the burning rate is thereby increased and the flame length reduced. The disposition of cooling surface in the combustion chamber is largely a matter of boiler design, but providing ignition is not retarded the maximum of furnace cooling surface should be installed, and for this purpose bare boiler tubes provide the maximum heat absorption possible."

## Fly Ash Applications

An increase in the number of pulverized coal installations and the growing use of fly ash recovery equipment again raises the question of useful disposition of the fly ash thus recovered. Research and experiments have long been under way in an effort to find commercial applications of this bulk product, as a result of which it has found use to a limited extent in the manufacture of portland cement, in light-weight concrete, as a filler in the manufacture of rubber products, as insulation and for building blocks.

The last-named application, under the Rostone patents, has been developed for several years by the Detroit Edison Company. As brought out in a recent discussion by J. R. James of that company, to date there have been constructed ten homes, ranging in value from $3000 to $10,000, two churches and several breweries. Also, the company is now constructing a six-story service building which will employ more than 100,000 such blocks and all the floors of which are formed of fly-ash cinder concrete. The high insulating properties of the fly ash are utilized by inserting it into the hollow cells of the block.

Obviously, few power companies are in a position to set up organizations to handle commercially the fly ash from their pulverized coal furnaces. This can best be handled by independent interests, but the Detroit Edison Company deserves credit for having pioneered in this work and has demonstrated that such ash can be put to a useful purpose.

# Utility Plant Supplying Steam to Packing Houses

**This steam plant is being constructed by the Nebraska Power Company adjacent to the packing plants of Armour & Company and Swift & Company, to both of which it will supply steam and electricity. The plant is of semi-outdoor construction and is designed for steam conditions of 525 lb gage pressure and 760 F total steam temperature. The initial installation consists of two 200,000-lb per hr steam generating units, fired with natural gas or oil, and supplying steam to a 5000-kw turbine-generator which exhausts at 20–40 lb and is provided with extraction at 160–190 lb. Because operating conditions may require practically 100 per cent makeup special attention was given to the system of feed-water treatment which is described.**

**By LOUIS ELLIOTT**

**Consulting Mechanical Engineer, Ebasco Services, Inc., New York**

THE Nebraska Power Company, supplying electric energy to Omaha and the vicinity, has its main station on the Missouri River in an industrial section of the city. Its total installed capacity is something over 100,000 kw, including the most recent extension —a 10,000/12,500-kw, 1200-lb, 900-F superposed turbine-generator.

### *Service to Packing Industry*

The important meat packing industry in South Omaha has been supplied with its electrical requirements by the Nebraska Power Company, the packers providing a low-pressure boiler plant for the supply of steam for process and miscellaneous uses.

After careful study extending over a period of years, by engineers of utility and packing companies, plans have been worked out for construction by the Nebraska Power Company of a steam plant adjacent to the packing plants, to be known as the South Omaha Steam Electric Station. New contracts have been negotiated between the Nebraska Power Company and two of its most important customers, Armour & Company and Swift & Company Inc., looking to a supply from this new station of steam for process and miscellaneous uses, and of electrical energy. Construction is actively under way for trial operation of the plant during the Spring of 1938.

Utility-industrial relationships of this character, providing as they do for supply of steam as well as electricity, and thus effecting an additional tie between operations of buyer and seller, are more complex than the usual contract covering the sale of electrical energy only. It is therefore desirable that the best commercial and engineering ability be applied, during negotiations leading up to such a contract, to the end that terms shall be fair to both parties, and the results profitable to both, through the contract period. A plant of the kind contemplated, supplying steam and generating "by-product" energy, introduces certain economies as compared with condensing operation, the benefits of which should be equitably distributed between purchaser and seller.

Investigations preliminary to negotiation of the contract, and to choice of steam conditions and design of plant, were quite extensive and complicated. It was necessary to take into account probable growth of the steam and electrical loads in the packing-house district, expected relationship between consumptions of steam at the two utilization pressures (160- and 20-lb gage, respectively), and availability of electrical energy from sources other than the new plant. The solution arrived at represents the compromise best suiting combined requirements, and making possible most reasonable rates to the packing companies.

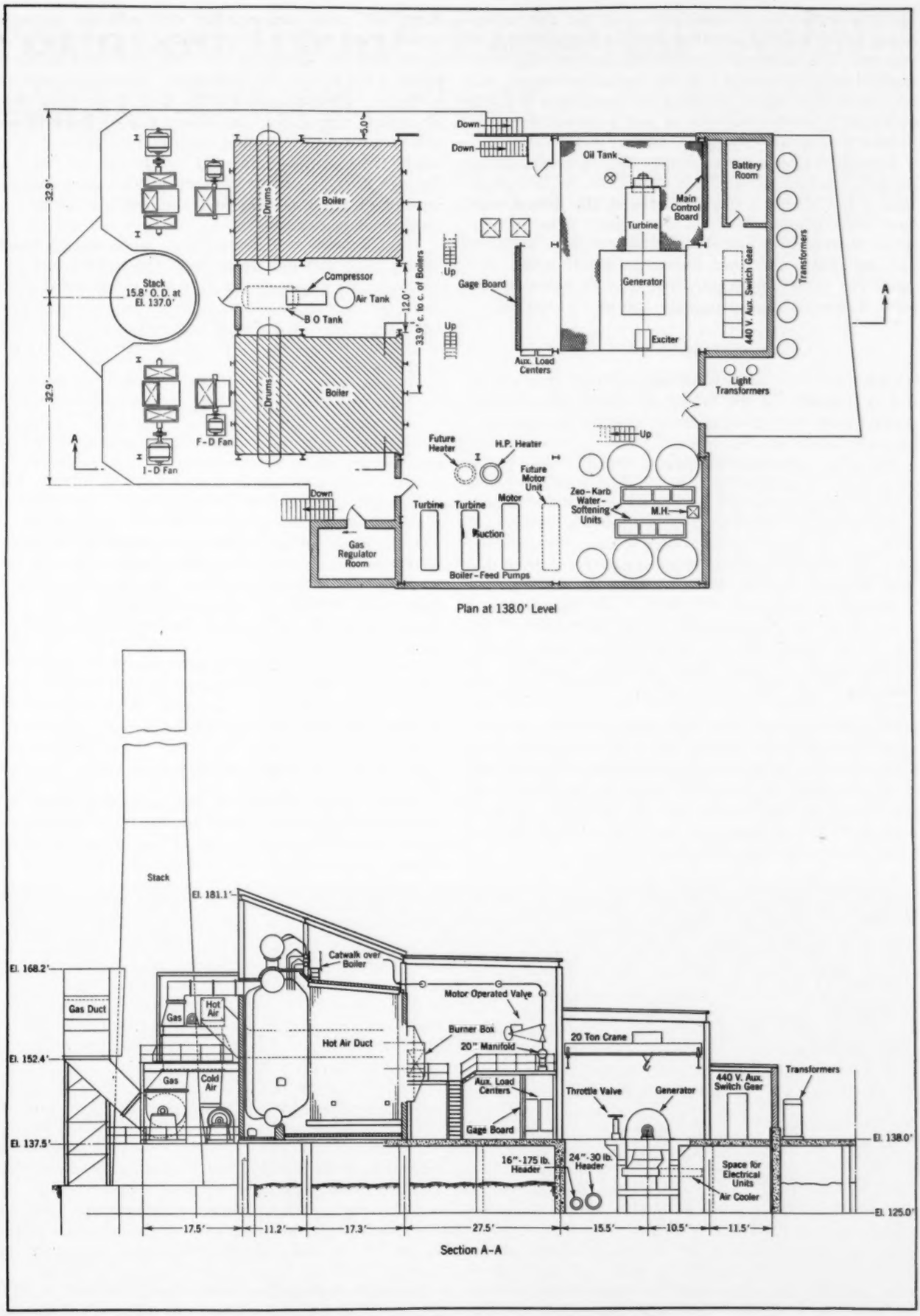
Contract with Armour & Company, and similarly with Swift & Company Inc., calls for delivery of a maximum number of pounds of steam hourly, together with electrical power and energy as required. Steam is to be delivered to the customers at 160- and 20-lb gage, and electric energy as 3-phase, 60 cycles, the rates being specified by demand and energy components for steam and for electricity. Customers' boiler plants are to be utilized as reserve low-pressure steam capacity.

### *Site and Structures*

In view of the desirability of short steam lines from the new South Omaha plant to the packers, choice of site was quite closely circumscribed. A triangular tract, adjacent to Armour property and not far from Swift, conveniently served by railway spur and from highway, was selected.

The illustrations show an outline plan of the development, and a sectional elevation, covering the arrangement of major equipment.

For the benefit of the parties to the contract, development is to be made at the lowest practicable cost, and the location selected made it practicable to minimize expenditure for architectural appearance. The building is of simple type, with structural steel frame, and designed rather closely to suit the equipment. It was planned that corrugated asbestos should be used for all




**Plan and sectional elevation of South Omaha Steam Plant**

building walls, but it was found that for the turbine room, brick could be substituted at moderate additional expense. The boilers are of semi-outdoor type, with a corrugated-asbestos canopy over the top and extending part way down the sides. Housing for protection of boiler operators, provided in front of and between the units, utilizes corrugated asbestos-protected metal siding.

Possible flood conditions dictate that the main operating floor shall be placed about 13 ft above original grade. Had it not been for this requirement the design could have been made still more economical. The turbine-room basement is made water-tight up to elevation 138, but the boiler-room basement is left open. Soil conditions call for 60-ft piles cut off well below ground level, a total of approximately 500 being required.

### *Boiler Equipment*

Base fuel is to be natural gas, with oil reserve. It will be possible, in the future, to change over to pulverized coal, but investment to provide for this contingency is kept at a minimum.

The boiler equipment consists of two 200,000-lb per hr Combustion Engineering Type VU two-drum bent-tube boilers, designed for 525 lb per sq in., with a furnace width of 19 ft, 11,800 sq ft boiler heating surface and 3300 sq ft of projected water-wall surface. Each boiler has a 36-in. bottom drum, 48-in. upper steam drum and 48-in. diameter dry drum. A bubble-type steam washer is located in the upper dry drum. The superheater is designed to give approximately 760 F at loads from 125,000 to 200,000 lb per hr. Boiler setting walls involve various types of construction, including firebrick, tile, insulating block, rock wool, asbestos cement and steel casing.

Four Forney combination gas-and-oil burners are provided for each boiler, taking gas at 15 lb gage pressure. Each boiler is equipped with one 20,000-sq ft Ljungstrom air heater with a separate 12-in. top element to permit convenient replacement in case of corrosion. Forced-draft and induced-draft fans, one of each per boiler, are driven by constant-speed motors.

A large saving is effected in this station by utilizing semi-outdoor type of boilers, omitting conventional full housing. The sketch shows an outline of the housed operating space, between turbine room and firing front of boilers, and between boiler units. As indicated, the boiler manufacturer provides a canopy above the boilers, extending part way down the sides, but with these exceptions the steam-generating units are exposed to the weather, suitably water-proofed and with careful protection against freezing troubles during cold weather. The size and arrangement of the boilers and housing, are indicated, together with an outline of the concrete foundation extending around and to the rear of the boilers, supporting the fans and drives. The forced- and induced-draft fans are placed outdoors, with their motors protected from weather.

### *Water Treatment*

An important element of the plant is the water-treating equipment. Some condensate may be returned from the customers, but the boiler plant is designed for 100 per cent makeup. A study, comparing various methods of treatment, resulted in choice of two Zeo-Karb "H" units each supplied with sufficient zeolite to soften about 600,000 lb of Omaha city water in seven hours, and two Zeo-Karb "S" units each with zeolite to soften 1,000,000 lb in seven hours. Treating equipment includes acid tank, acid-dilution tank, brine tank, phosphate-feed apparatus, degasifier, rate-of-flow controls and valves. Under normal conditions 37 per cent of the water passes through the "H" units and 63 per cent through the "S" units, going thence to a mixing chamber on top of the degasifier and through the latter to a treated-water storage tank.

Treated feedwater is heated in a deaerating heater taking 30-lb exhaust steam from the turbine and in a closed heater taking steam from the 175-lb bleed point. Both the deaerating heater and the boiler-feed storage tank are located in a special high section of the building, to give approximately 20 ft head above the center line of the boiler feed pumps.

### *Turbine Equipment*

For the present, one 5000-kw, 0.8-pf, 450-lb, 750-F General Electric steam turbine-generator, to be bled at 175 lb and to exhaust at 30-lb gage, is to be installed. This unit is also rated at 6250 kw at 1.0 pf. The turbine is designed for maximum steam flow to the throttle of 200,000 lb per hr, and maximum exhaust of 100,000 lb. Extraction pressure is adjustable between 160 and 190-lb gage, and exhaust pressure between 20-and 40-lb gage. The generator is wound for 13,800 v, and is to be connected to the 13-kv bus of the present Swift-Armour substation.

The plant is so designed as to be capable of convenient extension by one or more turbines, with corresponding boiler equipment, but a minimum is to be expended looking forward to any specific expansion.

### *Piping Arrangement*

Station piping is simple in design, welding being used wherever practicable. There are two main low-pressure headers, one connected to the 175-lb extraction of the turbine, and supplied also through the 450/175-lb reducing station, with maximum capacity of the valve throat of 200,000 or 250,000 lb per hr. The other low-pressure heater is connected to the 30-lb exhaust of the turbine, and supplied also by a reducing valve from the 175-lb header. Transport lines to the packers run from the 175-lb and 30-lb headers, each being supplied with a desuperheating station. Customers' steam requirements, in excess of that supplied by the turbine at the two pressures, are to be supplied through the reducing valves.

Feedwater is heated by a blow-down heat exchanger; by a deaerating heater taking steam from the 30-lb header and delivering water to the boiler-feed storage tank; and by a high-pressure closed heater taking steam from the 175-lb header. Feed pumps take water from the boiler-feed storage tank and deliver through the closed heater. These pumps utilize steam from the 175-lb header and exhaust into the 30-lb header. Final details of the heat balance are not available at this writing.

Steam transport lines include a 175-lb and a 30-lb line, one branch of each running to Armour and another to Swift. Transport piping is to be welded.

# Tests on Draft Fans for Logan Steam Plant

By THEODORE BAUMEISTER, JR. and S. N. FIALA

American Gas and Electric Company

**Tests on the forced- and induced-draft fans for the million pound per hour boiler at Logan were conducted at the manufacturer's plant. In the case of the forced-draft fan the required loading was applied on a circular discharge duct with the fan driven by an electric dynameter, but with the induced-draft fan it was necessary to utilize horizontal test ducts on the inlet side and free atmospheric discharge on the outlet. The test results are here given.**

IT IS not customary to conduct acceptance tests on fans for boiler service but in the case of the new high-pressure installation at the Logan, West Virginia, plant of the Appalachian Electric Power Company, precedent was set aside and complete tests were run on the forced- and induced-draft fans at the Hyde Park factory of The B. F. Sturtevant Company. The decision to make these tests was prompted by several considerations.

The Logan boiler which will produce steam at the rate up to 1,000,000 lb per hr is to be the only boiler in the station to serve the topping unit and the low-pressure turbines having a combined capacity of about 90,000 kw. The existing low-pressure boilers, having an equivalent capacity of about 40,000 kw, will be out of active service when the topping unit is in operation.

Every precaution has been taken to make the high-pressure boiler as reliable as possible, this procedure dictating a comprehensive check of the auxiliary equipment by actual tests as far as it was practical, so as to preclude boiler outage for alterations to this class of apparatus. In the event of interruption in the output of the high-pressure boiler, several hours would be required before the low-pressure boilers could pick up a portion of the plant load.

This single boiler arrangement not only dictates utmost reliability but, being of such large size, requires equipment capable of maintaining high operating efficiencies over long periods of continuous operation.

The fans, as a consequence of the large gas volume and high drafts, require in the case of the induced draft, 1400-hp turbines to drive them. These auxiliary turbines would be main units in many industrial power plants and they bespeak the size of the fans which they drive. While the fans are not the largest ever constructed for boiler service, they are close to that upper limit. Their design was based on the customary practice of extrapolating the fan laws from model or previously tested fan sizes. The adequacy of the fan laws to produce the predicted fan characteristics by extrapo-

Fig. 1—Induced-draft fan test setup at the builder's works

lation from model to prototype was therefore one general purpose of the tests. In addition, the tests, it was felt, would serve as a check on the manufacturing technique and the character of the workmanship encountered in fabrication. Many minor alterations and adjust-

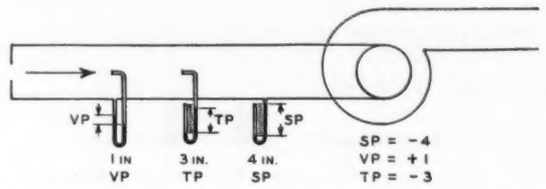



**Fig. 2—Typical pitot tube readings on an inlet-fan duct**

ments can be made prior to installation which will facilitate the connection and operation of control equipment for higher boiler economy.

Tests on the induced-draft fans were further desirable because it was anticipated that dust separating vanes would be installed in the inlet scrolls as part of a fly ash collector system. The rigorous knowledge, from test of the fan unit performance itself, it was expected, would be of material assistance in the proper design and application of this dust collecting equipment. Therefore, to provide basic information for these numerous purposes the decision was reached to conduct the acceptance tests.

### *Test Methods*

The fans were purchased under contract which specified testing methods in accordance with the Code of the National Association of Fan Manufacturers. In the case of the forced-draft fan no problem was encountered in the use of the Code. The required loading was applied on a circular discharge duct with the fan driven by an electric dynamometer. On the induced-draft fan, the test procedure was not as simple as with the forced-draft fan.

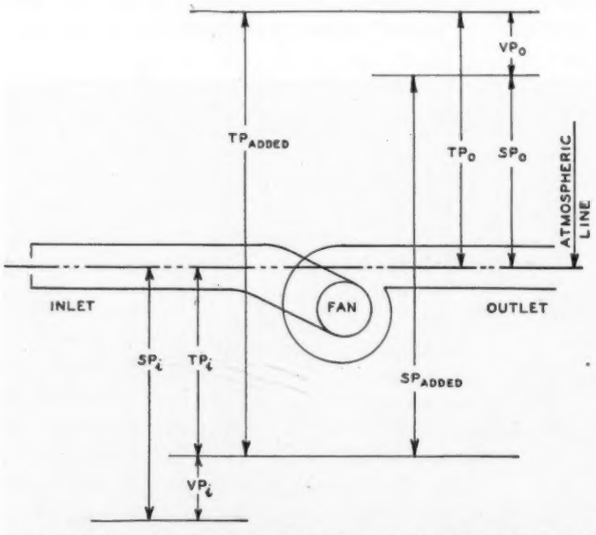



**Fig. 3—Schematic diagram to define pitot tube readings on inlet and discharge ducts**

In fact, the Code was inadequate for the purposes. The design of the connection of the fans to the boiler unit required inlet and outlet flow directions which made it impossible to take pitot tube readings on the discharge duct. If the Code had been rigorously followed to get such readings, it would have been necessary to carry a 10-ft duct some 100 ft up into the air and inclined at an angle of 15 deg to the vertical. This construction was precluded for evident reasons and it was necessary to substitute a procedure utilizing horizontal test ducts on the inlet side and free atmospheric discharge on the outlet. Fig. 1 is a photograph which shows the arrangement employed.

This arrangement is not in accordance with the Code. There is no reason, however, why the results of a test on

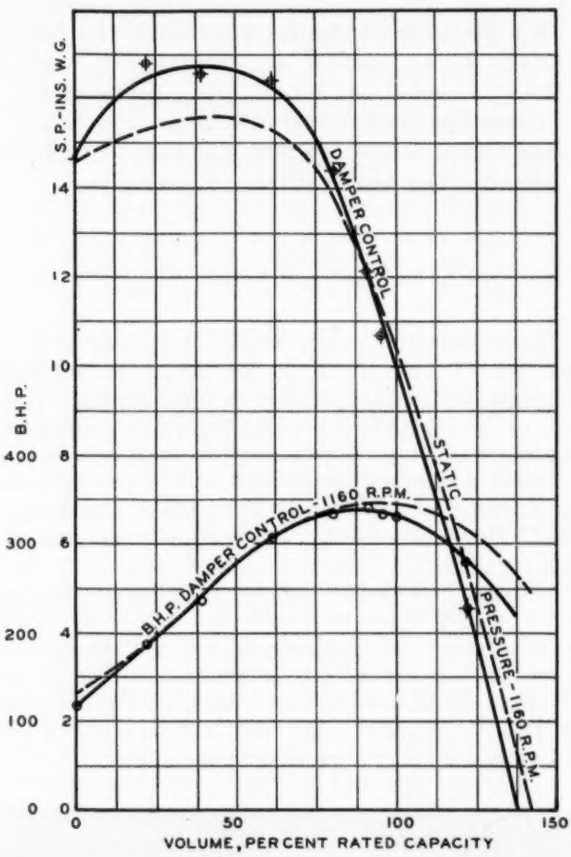



**Fig. 4—Forced-draft fan test results with inlet vanes wide open**

the inlet duct are not in every respect just as reliable and accurate as those on a discharge duct. There can and will be, nevertheless, much confusion on the interpretation of pitot tube readings because of the inadequacy of the English language. The static pressure reading on the inlet duct is *not* the static pressure on the fan. The correctness of this statement is brought out in the discussion of the paper by Stuart and Somers[1] and by consideration of Fig. 2. Here there is a fan with an inlet duct and the three pressure readings obtained on a pitot are shown expanded. As the pressure in the duct is below atmosphere the static tube would read, say, as shown, $SP = -4$ in. The velocity head, which is always positive, would be $VP = +1$ in. The total pressure, which is the algebraic sum of the $SP$ and the $VP$, is then $TP =$

[1] Stuart and Somers, "The Definition of the Quantity Head Characteristics of Fans," *Trans. A.S.M.E.*, 57, 433-8(1935).

$-4 + 1 = -3$ in. This result appears, on its face, to be incongruous because the total energy is less than the static. If, on a fan, the inlet and outlet ducts are of the same diameter, the total head reading ($TP = -3$ in.) is the actual static head that the fan is developing. The 1-in. velocity head, which is positive, is not contributed by the fan but by the ambient atmosphere.

Another way of viewing the same matter is illustrated in Fig. 3. If a fan is considered to be at the atmospheric line with both inlet and outlet ducts connected to it, then the respective pitot tube readings can be laid off vertically as shown. If friction is omitted then the head developed by the fan is as shown by the "added" items. The total pressure developed by a fan is defined as the

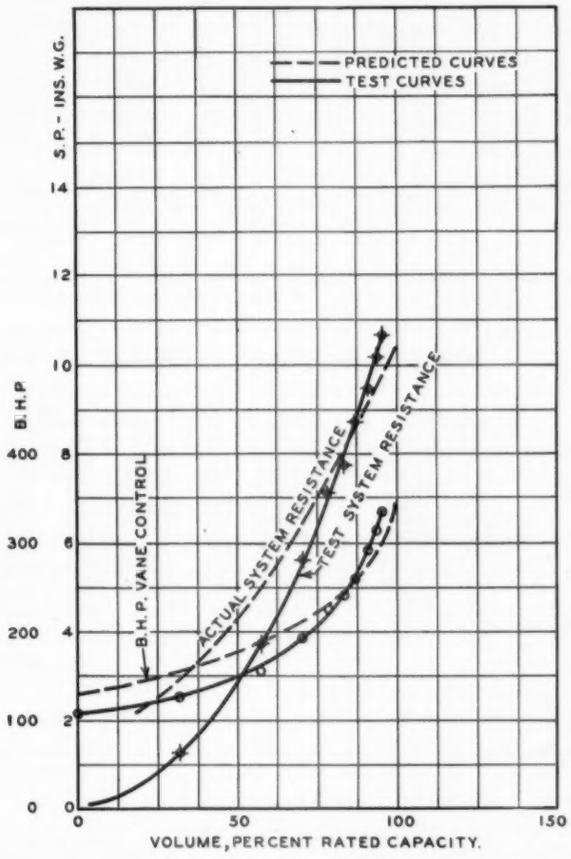



**Fig. 5—Forced-draft fan test results with inlet vane control of capacity. $D_2$ = 59 in.; $D_1$ = 47 in.; gas density = .071 lb per ft³; rpm = 1160 radial depth; heel = 48 in., tip = 31.5 in.; with Hagen inlet vanes**

sum, $TP$ added = $TP_i + TP_o$. The static head developed by the fan is defined as the total or impact head minus the velocity pressure in the outlet duct or $SP$ added = $TP_i + TP_o - VP_o$. Under actual conditions of operation allowance must be made for duct friction between the traverse stations so that from the figure:

Static head developed by fan =

$SP$ added + duct friction.

In the illustration it is easy to shift the position of the atmospheric line to simulate the omission of either the inlet or the outlet duct and to demonstrate that the static head developed by a fan which discharges directly to the atmosphere is that given above. In this manner it is possible to test the fan on the inlet side and yet comply with the intent of the Code.

### *Results of Tests*

The results of the tests are shown in Figs. 4 to 7, together with the estimated performance data. In the

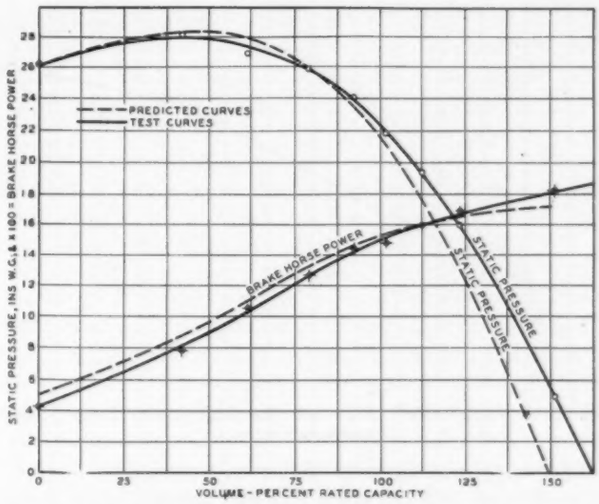



**Fig. 6—Induced-draft fan test results. $D_2$ = 81½ in.; gas density = 0.050 lb per ft³; rpm = 1110; spiral inlet boxes**

computation of brake horsepower the electrical method using stray power losses on the calibrated motor was given preference to the direct reading of torque from the weight loadings on the dynamometer arm. This decision was prompted by the greater consistency of readings with the former method.

Fig. 4 shows the forced-draft performance with the inlet vane control mechanism wide open. Comparison of test results with the predicted values at rating shows that the fan is short on pressure by about 4 per cent but better on power consumption by about the same amount.

Fig. 5 shows the results of using the inlet vane control mechanism for variation of capacity on the forced-draft fan. The saving in power input over straight damper control is obvious. The exact duplication of the estimated system resistance curve of the boiler could not be made in the available test time so that exact comparison between predicted and actual values is not possible in the figure. The test was accordingly conducted by setting the throttle in the discharge duct to a value of 100 per cent rated capacity with the inlet vanes wide open. Smaller capacities were then obtained by changing the inlet vane setting without altering the discharge duct throttle position. The resultant test system resistance therefore followed from the flow circumstances of the test and the horsepower as recorded. During the test it was demonstrated that inlet vanes alone did not give "blocked-tight" conditions and with the vanes entirely closed, there was still a flow through the fan of roughly 20 per cent of rated capacity. This leakage can and will be reduced by careful field fitting of the inlet vanes.

The results of the induced-draft fan test are given in Fig. 6 with the same general conclusions prevailing as with the forced-draft fan. The actual test figures gave lower pressures and less horsepower than predicted. These differences were considered negligible. As a fur-

ther step in the tests the induced-draft fan inlet scrolls were equipped with dust separating vanes and the influence of these vanes on the fan power requirements are shown in the plot of Fig. 7. Here the brake horsepower

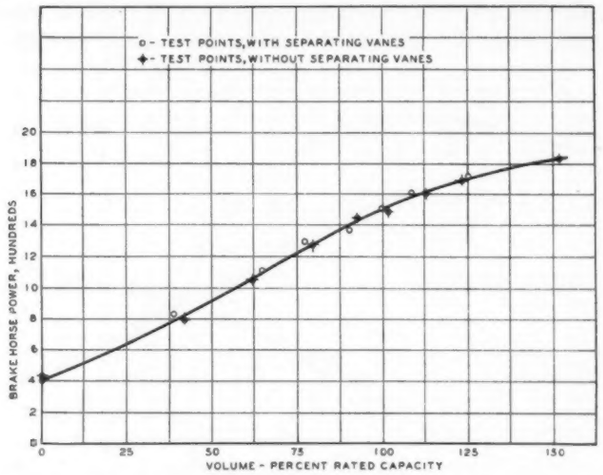



**Fig. 7—Induced-draft fan test results, mean horsepower characteristics**

curves, with and without vanes, are shown to be substantially one and the same line and indicate their small influence on this element of fan performance.

*Conclusions*

As a consequence of these tests it was concluded that although the manufacturer's guarantees were not complied with strictly they were substantially. The tests demonstrate that the usual fan laws are adequate for the case at hand in the extrapolation of performance values from model to prototype—a check of theory against practice that is often taken for granted. The information made available by the tests assures the attainment of boiler performance as far as fan limitations are concerned. The operators will know definitely what to expect from the fans whether they are operated singly or in parallel. This is especially pertinent because of its effect on the stability of the automatic control system. The knowledge of the exact limitations of the induced-draft fan performance will be of material assistance in the attainment of the desired dust collecting efficiency. Other benefits have resulted, not the least of which is a general raising of the level of manufacturing engineering precision that always accrues from cooperation of this kind between manufacturer and user.

## Water-Cooled Stokers

In the abstract of the paper by C. W. E. Clarke before the Association of Iron and Steel Engineers, which appeared on page 42 of the November issue of COMBUSTION, there is the following statement:

"The water cooling is not in the boiler circulation and, of course, in some cases this works to a disadvantage in a proper heat cycle."

I wonder whether Mr. Clarke intended to say this. So far as we know the only commercial water-cooled stokers in operation are our own, and all of these are cooled by water that is part of the boiler circulation.

(Signed) J. S. Bennett, Mechanical Engineer,
American Engineering Company

# EQUIPMENT SALES

## Boiler, Stoker, Pulverized Fuel

**as reported by equipment manufacturers of the Department of Commerce, Bureau of the Census**

### Boiler Sales

| | 1937 Water Tube | | 1936 Water Tube | | 1937 Fire Tube | | 1936 Fire Tube | |
|---|---|---|---|---|---|---|---|---|
| | No. | Sq Ft | No. | Sq Ft | No. | Sq Ft | No. | Sq Ft |
| Jan..... | 53 | 261,368 | 57 | 287,855 | 64 | 83,389 | 23 | 24,954 |
| Feb..... | 53 | 206,957‡ | 76 | 408,635 | 71 | 87,083 | 47 | 50,094 |
| Mar..... | 142 | 758,733 | 77 | 325,479 | 149 | 210,233 | 53 | 47,411 |
| Apr..... | 63 | 333,169 | 66 | 339,413 | 73 | 67,937 | 74 | 97,401 |
| May..... | 113 | 589,347 | 63 | 328,872 | 82 | 129,782 | 69 | 92,403 |
| June..... | 76 | 330,524 | 145 | 533,703 | 76 | 99,335 | 104 | 131,764 |
| July..... | 82 | 348,417 | 111 | 510,324 | 80 | 98,258 | 74 | 99,479 |
| Aug..... | 67 | 270,646 | 121 | 534,525 | 106 | 136,401 | 85 | 117,834 |
| Sept..... | 56 | 238,146 | 82 | 371,790 | 76 | 101,524 | 82 | 92,919 |
| Oct..... | 65 | 254,073 | 100 | 401,479 | 55 | 58,190 | 75 | 79,612 |
| Nov..... | 41 | 247,882 | 84 | 557,016 | 44 | 49,544 | 55 | 64,068 |
| Jan. to Nov. Inclusive.... | 811 | 3,871,697 | 982 | 4,599,091 | 876 | 1,121,676 | 741 | 897,939 |
| 1936—12 mos..... | | | 1,179 | 6,086,787 | | | 817 | 980,130 |

### Mechanical Stoker* Sales

| | 1937 Water Tube | | 1936 Water Tube | | 1937 Fire Tube | | 1936 Fire Tube | |
|---|---|---|---|---|---|---|---|---|
| | No. | Hp | No. | Hp | No. | Hp | No. | Hp |
| Jan..... | 63 | 25,278 | 24 | 10,657 | 141 | 21,786 | 139 | 16,840 |
| Feb..... | 45 | 16,591 | 30 | 11,693 | 120 | 20,650 | 98 | 13,567 |
| Mar..... | 80 | 38,074 | 28 | 10,250 | 179 | 24,709 | 105 | 14,605 |
| Apr..... | 72 | 37,185 | 56 | 30,686 | 154 | 23,064 | 99 | 12,844 |
| May..... | 65 | 26,327 | 36 | 16,742 | 137 | 21,443 | 150 | 21,326 |
| June..... | 49 | 19,787 | 58 | 27,546 | 186 | 26,627 | 186 | 23,171 |
| July..... | 79 | 29,207 | 81 | 31,603 | 251 | 34,253 | 255 | 35,615 |
| Aug..... | 58 | 21,998 | 98 | 34,308 | 394 | 53,096 | 336 | 45,960 |
| Sept..... | 40 | 11,359 | 62 | 24,416 | 384 | 46,893 | 437 | 50,690 |
| Oct..... | 53 | 17,727 | 61 | 26,367 | 310 | 39,837 | 401 | 62,763 |
| Nov..... | 31 | 12,171 | 51 | 16,420 | 190 | 21,525 | 273 | 46,260 |
| Jan.to Nov. Inclusive.... | 635 | 255,704 | 585 | 240,688 | 2,446 | 333,883 | 2,479 | 343,641 |
| 1936—12 mos. | | | 649 | 276,687 | | | 2,724 | 386,868 |

* Capacity over 300 lb of coal per hour.

### Pulverizer Sales

| | 1937 Water Tube | | | 1936 Water Tube | | | 1937 Fire Tube | | | 1936 Fire Tube | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. | | Cap. Lb | No. | | Cap. Lb | No. | | Cap. Lb | No. | | Cap. Lb |
| | N.† | E.† | Coal/Hr | N.† | E.† | Coal/Hr | N.† | E.† | Coal/Hr | N.† | E.† | Coal/Hr |
| Jan.... | 35 | 7 | 554,900 | 16 | 4 | 235,500 | — | 2 | 1,700 | — | 1 | 1,000 |
| Feb... | 2 | 6 | 68,300 | 9 | 8 | 165,100 | — | 4 | 3,600 | — | 7 | 7,700 |
| Mar... | 59 | 3 | 677,440 | 10 | 6 | 135,300 | 1 | 1 | 2,000 | — | 1 | 800 |
| Apr... | 24 | 1 | 257,100 | 35 | 3 | 639,050 | — | 2 | 1,100 | — | 1 | 1,200 |
| May.. | 22 | — | 276,800 | 22 | 1 | 188,900 | — | — | — | — | 1 | 1,000 |
| June.. | 15 | — | 99,150 | 24 | 7 | 196,100 | — | — | — | 3 | 3 | 10,400 |
| July... | 5 | 6 | 44,250 | 8 | 13 | 158,150 | — | — | — | — | — | — |
| Aug... | 8 | 15 | 211,400 | 18 | 11 | 304,500 | — | — | — | — | 2 | 800 |
| Sept.. | 14 | 3 | 75,900 | 11 | 1 | 82,200 | 2 | — | 2,500 | — | — | — |
| Oct... | 10 | 16 | 302,450 | 13 | 1 | 135,500 | — | — | — | 1 | — | 1,000 |
| Nov.. | 7 | 8 | 220,000 | 24 | 3 | 316,400 | — | 1 | 1,000 | — | 2 | 1,200 |
| Jan. to Nov.Inclusive | 201* | 65 | 2,819,890*‡ | 190 | 58 | 2,556,700 | 3 | 10 | 11,900 | 4 | 18 | 25,100 |
| 1936—12 mos. | | | | 269 | 71 | 3,633,845 | | | | 4 | 24 | 30,600 |

† N—New boilers E—Existing boilers.
* Not including 5 new boilers for storage system.
• Not including 167,000 lb coal/hr for storage system.
‡ Revised as a result of correspondence correcting data for February and March.

# Combustion of Pulverized Coal

By HENRY KREISINGER

Combustion Engineering Company, Inc.

**This paper, which was presented before the joint meeting of the Detroit Section, A.S.M.E. and the Canadian Institute of Engineers, on November 16, deals with the combustion of pulverized coal with special reference to water-cooled furnaces. It discusses the effect of various factors on the ignition and follows the process of combustion through the furnace. The factors that are given consideration are the amount of primary air, admission of secondary air, fineness of coal, the percentage of moisture and volatile matter in coal, characteristics of ash, mixing, oxygen concentration and the furnace temperature. It is shown that beyond the temperature required for quick ignition nothing is gained by going to higher temperature. The following is an abstract of the paper which, together with the rather extensive discussion, will likely appear at a later date in the Transactions of the Society.**

THE two most outstanding features in the progress of steam-generating equipment within the last 15 or 20 years are the application of pulverized fuel and development of the water-cooled furnace. The development of one of these stimulated that of the other. Water-cooled furnaces not only made possible very large steam-generating units and high rates of combustion, but also practically eliminated furnace maintenance. Being built of tough steel they can be made large, and expansion and contraction can be easily taken care of because the temperature of the water-cooled walls varies over a much smaller range than that of refractory walls. Temperature of the metal in water-cooled furnaces varies over a range of about 500 deg F, whereas that of refractory walls varies over a range of 2000 deg F.

High rates of combustion can be employed because the sweeping of the burning mixture over furnace walls does not damage water-cooled steel walls. Such combustion rates require intensive mixing in the furnace and this is always accompanied by sweeping of the flame over the furnace walls. Without intensive mixing at high rates of combustion many of the larger coal particles would pass out of the furnace only partly burned and the flue dust would run high in combustible.

Water-cooled furnaces absorb large quantities of heat thereby lowering the temperature of the furnace gases and that of the ash carried by the gases, so that there is less tendency for these ash particles to stick to the boiler tubes and to the superheater elements.

A general impression prevails that it is difficult to light a fire in a water-cooled furnace, that the fires are unstable at low ratings and that the absorption of heat by the walls retards combustion. These drawbacks are more imaginary than real. Refractory furnaces are just as cold as water-cooled furnaces when the fires are started, and the stability of flame at any rating is largely a matter of burner design, air adjustment and a steady fuel supply. For easy lighting and stable flames at low ratings the burners should be so designed that only part of the air needed for complete combustion is supplied with the coal. This makes a rich mixture which ignites readily. Because of this small weight of air the mixture is heated quickly to ignition temperature. When we start a cold automobile engine we choke the air to obtain a rich mixture which ignites readily. In a boiler furnace the additional air needed for complete combustion should be supplied beyond the zone of ignition.

Beyond the temperature required for quick ignition of the fuel nothing is gained by going to higher temperature. In fact, there are experimental indications that high temperatures retard the combustion.

### *Nature of Pulverized Coal*

Pulverized coal is a mixture of small particles of coal varying in sizes from about one millionth part of an inch to about one fiftieth part of an inch, which is a very large range in sizes. If a sample of pulverized coal were magnified 1000 times, the smallest particles would appear the size of a grain of sand and the largest like boulders about 2 ft in diameter. Between these extremes there would be all the sizes imaginable, and many of the smallest particles would be seen clinging in clusters and others adhering to the larger particles.

Coal is reduced to pulverized form so that it can be kept in suspension and supplied to the furnace in a stream as a mixture of air and coal. The air gives the mixture its fluidity so that it can be handled and burned like gas. Another reason for pulverizing coal is to make it possible to bring the air more readily in contact with the surface of the coal particles. At 2000 F a piece of coal of one inch diameter requires for complete combustion a volume of air contained in a sphere one yard in diameter. If this were in the center of the sphere, the average distance of the oxygen molecules from the coal would be about 13 in. A particle having a diameter of 0.006 in., which is the largest size passing through a 100-mesh screen, requires a volume of air contained in a sphere of 0.22 in. diameter.

The fineness is determined by running a sample through a set of screens and obtaining the percentages going through each. The screen sizes usually employed are 200, 100, 50 or 40 mesh. For instance, the fineness may be described as 70 per cent through 200 mesh, 90 per cent through 100 mesh and 98 per cent through 50 mesh. The percentage on a 50-mesh screen should be small because this oversize coal usually does not stay in the furnace long enough to be burned to ash and much is deposited in the soot hoppers or carried out of the stack only partly burned. It is more important that the percentage on a 50-mesh screen be low than to have a high percentage go through a 200-mesh. The largest particles going through 200 mesh are about 0.003 in. diameter. The number of these large particles is comparatively small. Also, there are a great many small particles approaching one millionth part of an inch which are mere dust. These remain in suspension a long time, even in quiet air. Although their total weight is small their number is large. When pulverized coal is brought into a furnace these very fine particles ignite readily and burn quickly. They are depended upon to a large extent to start ignition.

### *Accurate Observations Difficult*

It is difficult and inconvenient to make accurate observation of a particle of coal burning in a boiler furnace. Most of the particles are small and hard to see; they also move fast and burn quickly. In some cases, however, when the percentage of oversize coal is high one can see the very large particles beyond the tips of the luminous flame as large flaming dots about a quarter of an inch in diameter. This apparently large size is due to the envelope of flame, indicating that the volatile matter is still coming off and burning. After all the volatile has been distilled and burned these burning particles appear as bright specks much smaller than the flaming dots.

When the coal particles enter the furnace they are rapidly heated and, as their temperature rises, moisture and volatile matter are driven off. The latter ignites and burns with a hot luminous flame. After the volatile matter has been distilled off and burned, the residue of fixed carbon starts to burn without visible flame and the combustion process proceeds to completion. The time required for combustion depends on the particle size, moisture content and volatile matter. Very small particles burn instantaneously, whereas the largest particles take one or two seconds or even longer, and many never burn completely. Coal with high moisture takes more time because this must be driven off first before the temperature can rise high enough to distill and burn the volatile matter. High volatile coal requires less time to burn because the volatile matter diffuses into the surrounding air and meets the oxygen half way, whereas the residue of fixed carbon remains and must wait until the oxygen comes to it. While the volatile is being distilled off, no oxygen can penetrate to the surface; in fact, the heat that reaches the surfaces of particles is used in distilling the volatile matter, and the fixed carbon does not reach the ignition temperature.

The various stages of combustion can be observed in detail by placing a small cube of coal, with a thermocouple in the center of it, in a laboratory muffle furnace heated to about 850 C. It will be seen that the heat absorbed by the cube during the first few minutes is used to drive off the moisture and volatile. The temperature of the fixed carbon does not rise appreciably until the volatile matter has been distilled off. Evaporation of the moisture and the distillation of volatile matter takes place first in the outer layer of the cube and gradually penetrates to the center. The edges and corners are more exposed to the heat and therefore absorb heat faster and lose the moisture and volatile in a shorter time. They are therefore brought to a glowing temperature before the body of the cube. When most of the volatile has been distilled off and oxygen comes in contact with the fixed carbon the latter starts to burn but the ash remains and gradually forms a protective layer of ash over the remaining fixed carbon. This layer of ash reduces the chances of the oxygen making contact with the fixed carbon under the ash layer. The oxygen that does penetrate combines with the fixed carbon to form $CO_2$ or other carbon compound. This $CO_2$ thus formed under the layer of ash has the same difficulty in penetrating the ash on its way out as the oxygen had on its way in. Thus, the $CO_2$ is delayed under the ash layer and is in the way of more oxygen making contact with the fixed carbon.

With pulverized coal the burning stages are much shorter but their relative length and sequence are the same. The length of the stages is greater with the large particles than with the small ones. The ash residue is also a greater hindrance to oxygen making contact with the remaining carbon because there is more of it in the larger particles. The character of the ash and its behavior at the furnace temperature has an effect on the contact making between the oxygen and the fixed carbon. The retarding effect of the ash is often attributed to the lower reactivity of the carbon.

### *Principle of Combustion in a Boiler Furnace*

The combustion process in a boiler furnace takes place in two steps; first, the bringing of the combustible in contact with the oxygen, and second, chemical combination after the two have come in contact. Obviously, the latter cannot occur any faster than the contact making. This is true whether the combustible is in a gaseous or a solid state. Above ignition temperature the chemical combination is instantaneous. Therefore, rapidity of combustion depends on the rapidity of oxygen coming in contact with the combustible. The rate of contact making determines the rate of combustion. This is a fundamental principle underlying combustion in boiler furnaces.

At lower temperatures the speed of chemical combination is about doubled for every 10-deg C temperature rise. We do not know how far up the temperature scale the doubling continues, but if we assume it holds between 100 C and 700 C, the latter point being approximately the ignition temperature of coal, the speed of chemical combination would be doubled sixty times. We know the speed is appreciable at 100 C and if this were doubled sixty times a very high speed would be obtained. If the speed at 100 C is equal to $R$, that at 700 C would be $R \times 2^{60}$; that is, $R$ times a figure with eighteen ciphers behind it.

It does not seem reasonable that the speed of chemical combination would double itself for every 10 deg C temperature rise over a wide range. It is certain that this doubling does not go up to 700 C. However, it is also

reasonably certain that the speed continues to increase although at a decreasing rate up to 700 C, and beyond that point to a considerably higher temperature. Eventually a temperature is reached beyond which there is not only no further increase in the speed, but a decrease; it perhaps would be more correct to say, until a point is reached at which the compounds dissociate as fast as they are formed. However, it is safe to assume that in a boiler furnace the speed of chemical combination is very high, and for all practical purposes is instantaneous at and above the ignition temperature. Hence the chemical combination takes place as fast as oxygen and combustible come in contact, and the rapidity of combustion depends entirely on the rapidity at which contacts are made.

The relation between the rate of combustion and temperature is represented graphically in Fig 1. The rate of chemical combination is very low at atmospheric temperature but increases rapidly as the temperature rises.

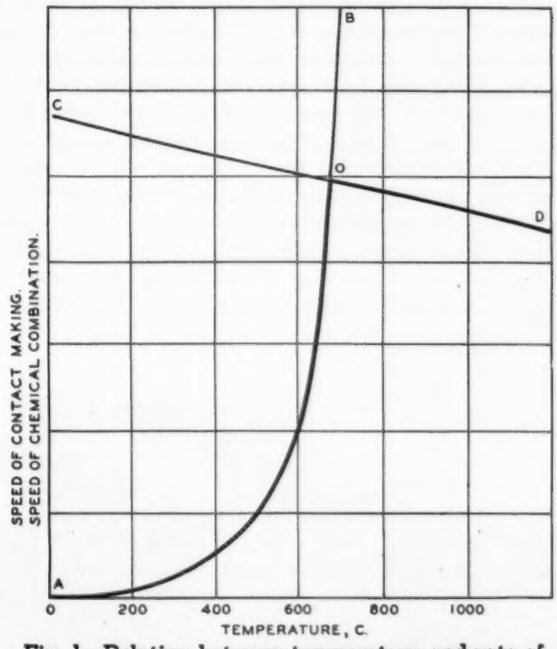



**Fig. 1—Relation between temperature and rate of combustion**

Curve *AOB* represents the variation of speed of chemical combination with temperature. Curve *CD* represents the speed of contact making. At the left of the intersection point *O* only some of the molecules of oxygen that make contact combine with the combustible; at the right of point *O* all oxygen molecules that make contact combine with the combustible. The speed of combustion is represented by the lines *AOD*.

It is represented by the curve *AOB*. The rate of contact making is represented by line *CD* crossing the curve *AB* at *O*. At low temperature many molecules of oxygen make contact with the coal particle but only comparatively few combine with the combustible. At these low temperatures the speed of combustion is equal to that of chemical combination. As the temperature rises increasingly a greater proportion of the molecules that make contact combine with the combustible until the point *O* is reached where all that make contact with the combustible combine with it. This point may be called the ignition temperature. Above this the speed of combination is as high as that of contact making, and the rapidity of combustion depends entirely on the rate at which contacts are made. The speed of combustion follows the line *AOD*, and if we wish to increase it we must raise the line *CD*, particularly the part *OD*. This is done mainly by increased mixing.

### *Designing Pulverized Coal Furnaces*

The problem for the designer is to provide conditions favorable to ignition temperature close to the burner, and rapid contact making in the burning mixture. The former are met by a small amount of air with the coal, fine pulverization and turbulence. When fires are started in a direct-firing system the mill is operated at a low milling rate with reduced air flow through it. Such operation results in fine pulverization. Rapid contact making is produced by intensive mixing of the burning mixture, and fine pulverization. Intensive mixing takes the burning particles from one place where most of the oxygen has been used up to another place where there is still free oxygen available. Fine pulverization brings the combustible close to the oxygen.

Bringing the ignition close to the burner is easier with coals high in volatile than with low-volatile coals. It is difficult with anthracite. The quantity of primary air should be just about enough to burn the volatile matter. With high-volatile coal the primary air can be 35 per cent of the total needed for combustion, but with anthracite less than 10 per cent. In other words, the amount of primary air expressed in percentage of total air is about equal to the percentage of volatile in the coal. This approximate rule is easier to follow in a storage system than with direct firing in which the air supplied with the coal cannot be reduced below the minimum at which the pulverizing mill can be operated satisfactorily.

### *Control of Primary and Secondary Air*

In vertical firing the coal is fired downward and the burning mixture makes an upward turn near the bottom of the furnace. Primary air brings the coal in through the coal nozzle, and a small amount of air is supplied through the burner around the nozzle. Secondary air is supplied progressively through air ports in the front wall after the mixture has ignited. This method of firing is well adapted to coals of very low volatile content.

With horizontal firing the coal is usually fired through round horizontal nozzles in the center of the burner. (See Fig. 2). The mixture of coal and primary air flows through the nozzle with a rotative motion which tends to concentrate the coal in a rich mixture near the nozzle walls. The rotative motion also causes the mixture to bush out when it leaves the nozzle and produce turbulence. Secondary air is supplied around the coal nozzle and enters the burner through a set of vanes in a number of streams so directed as to give the flow a rotative motion. This rotation keeps the air close to the throat of the burner and away from the mixture of coal and primary air. The underlying principle is to get the mixture thoroughly ignited before it is diluted by secondary air. This type of burner is rather sensitive to the volatile content and is not suited to coals very low in volatile, such as anthracite. With coals high in volatile the flame has a tendency to be drawn into the burner and may damage it by heat, unless the throat is made small. With coals low in volatile the ignition may start too far

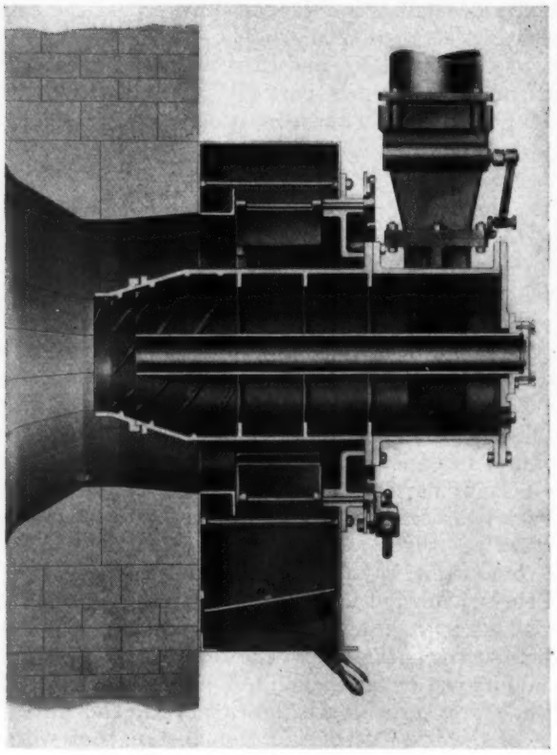


**Fig. 2—Burner for horizontal firing**

Primary air and coal move with a rotary motion through the coal nozzle. Secondary air moves with similar rotary motion outside of the coal nozzle and hugs the refractory throat of the burner. The mixture of primary air and coal ignites before the secondary air intermingles with it.

from the burner and be unstable; hence the throat should be large.

In corner firing there are one or more burners in each corner of the furnace, such as is illustrated in Fig. 3. Streams of coal and primary air are directed toward the center of the furnace, tangent to a small circle. Secondary air is supplied partly around the coal nozzles and partly through auxiliary air ports above or below the coal nozzles. The air around the coal nozzles is regulated to keep ignition close to the burners without backing into them. Most of the mixing occurs in the furnace where the streams of coal and air meet. This method of firing is adaptable to coals low in volatile.

### *Starting and Holding Ignition*

The mixture of coal entering the furnace is heated by the flame of the already burning mixture near the burner. This distills the volatile matter which makes a readily ignitible mixture with the primary air. When this mixture is ignited it burns with a hot luminous flame which radiates heat to the incoming mixture of coal and air. The hotter this flame the more heat is radiated by it to the incoming mixture, and the quicker the volatile matter will be distilled off and the gaseous mixture brought up to ignition temperature.

To hold ignition close to the burner the incoming mixture, or part of it, is brought in with a turbulence. That is, part of the stream of the mixture is made to branch off on each side of the main stream nearly at right angles to the general direction of flow. The initial velocity of the branched off part produces eddies or turbulence which reduces the movement of that part of the mixture in the direction from the burners into the furnace Thus, the velocity of the mixture in the coal nozzle before the branching off of parts of the stream may be 100 ft per sec. In the parts that are branched off two-thirds of this velocity may be spent in eddies or turbulence leaving only one-third in the original direction away from the burner. The slowing down in this direction causes the stream to bush out and expose a wider front to the radiant heat. The result is that this turbulent part of the stream becomes heated to ignition temperature before it moves an appreciable distance from the burner. Rapid heating of the mixture both before and after ignition causes it to expand and produce additional bushing out of the stream. The flame temperature after ignition has started is much higher than the ignition point.

### *Concentration of Oxygen in a Boiler Furnace*

When air is supplied to the furnace, it contains nearly 21 per cent oxygen. As combustion proceeds the oxygen is reduced at first very rapidly and then more slowly to about 2 per cent at the point where the gases leave the furnace. Simultaneously, $CO_2$ is formed taking the place of free oxygen. The very small coal particles burn first and the large particles burn only partially while the free oxygen is at high concentration. Their combustion must be completed after the concentration of free oxygen in the furnace gases has been reduced. It becomes increasingly more difficult for the unburned part of the large particles to make contact with the free oxygen, because these oxygen molecules are far apart and the inert gases are in the way of their free movement. If we had to depend on natural diffusion the rate of contact making would be slow. To speed this it is necessary to

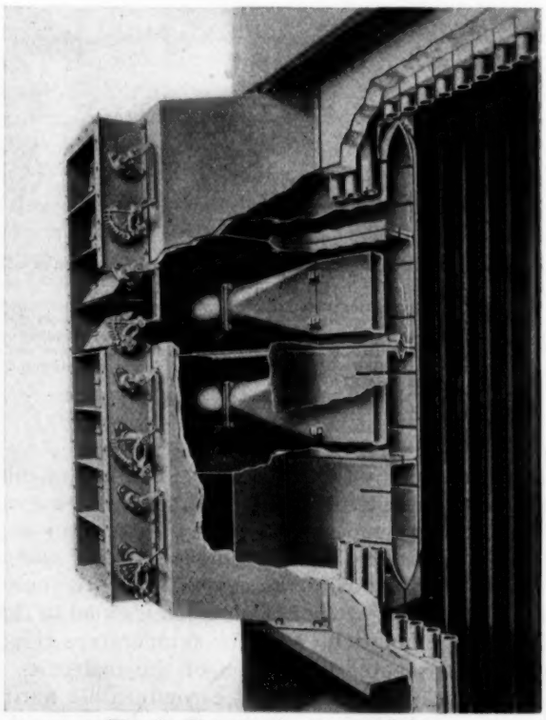


**Fig. 3—Burners for corner firing**

Primary air and coal flow through the coal nozzles. Secondary air flows through the air ports above and below the coal nozzles and intermingles with the coal mixture coming from the nozzles after ignition has started. When flame is too close to the burner some secondary air is admitted around the nozzles.

employ intensive mixing to move the coal particles out of one place where all the oxygen has been used up to another place where there are still some free oxygen molecules.

Mixing requires energy which is usually supplied in the form of high velocity air streams, so directed as to produce turbulence. Usually these air jets are made to impinge against one another, or give the burning mixture a rotative motion nearly at right angles to the general flow of the gases through the furnace. In this rotative motion the furnace walls play an active part, because they force the burning mixture to make turns. Only water-cooled walls can be used for this purpose.

### *Excessively High Temperature Not Needed for Quick Combustion*

Water-cooled furnaces absorb heat and thereby lower furnace temperature. Many are under the impression that this retards combustion. The basis for this impression is the common observation that rapid combustion is accompanied by high temperature and that high furnace temperature is necessary for rapid combustion. However, the fact is that rapid combustion causes the high temperature, and that the rapid combustion is caused by intensive mixing, fine pulverization or some other factors.

There is a good experimental evidence that high temperatures beyond the ignition point retard combustion. The table, herewith, is taken from Cooperative Bulletin 50, giving the results of experiments made at the U. S. Bureau of Mines. These experiments were made to determine the burning periods of carefully sized fuel particles at furnace temperatures varying from about 670 to 1000 C (1238 to 1832 F). The table shows that the burning periods are considerably longer at 1000 C than at 750 C. That is, raising the furnace temperature from 750 to 1000 C increased the time necessary for burning about 65 per cent.

TEMPERATURES AND INDICATED BURNING PERIODS OF CERTAIN SIZES OF FUELS

| Furnace Temp. °C | −50 + 60 Coal Milliseconds | −45 + 50 Semicoke Milliseconds | Coal, same weight particle as −45 + 50 Semicoke-Milliseconds |
|---|---|---|---|
| 750 | 282 | 275 | 214 |
| 800 | 317 | 308 | 240 |
| 850 | 367 | 342 | 276 |
| 900 | 386 | 374 | 308 |
| 950 | 438 | 410 | 336 |
| 1000 | 406 | 455 | 368 |

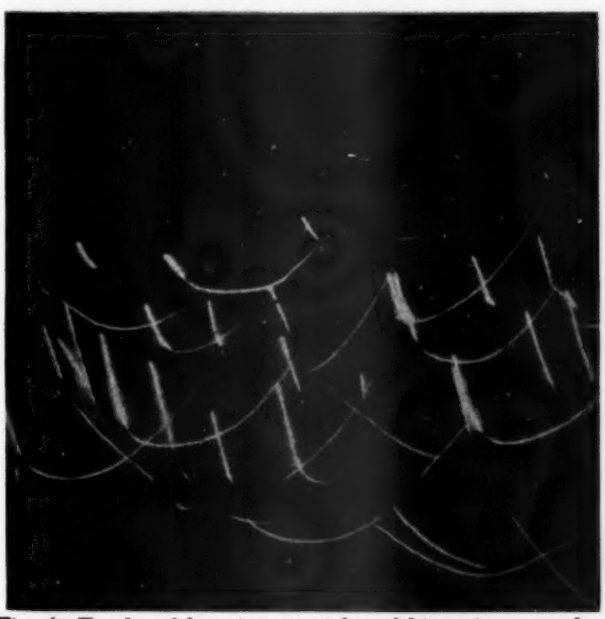


**Fig. 4—Tracks of burning particles of bituminous coal at 100 C**

Particles pass through 45- and remain on 50-mesh screen. The particles fall at first and then rise making a curved path on the film. The wide part of the path shows combustion of volatile matter.

### *Burning Particles Photographed*

These experiments were made in a small insulated furnace about 3 ft high and hexagonal in cross-section. Its sides were of nichrome ribbons and heated by passing electric current through them. Slots about $^1/_2$ in. wide in two opposite corners were covered by mica and formed windows for observation. During any one set of experiments the temperature was kept nearly constant. Carefully sized fuel particles were dropped in and the period of their combustion was recorded through the mica windows on a photographic film which was attached to a revolving drum. The burning particles showed tracks on the photographic plate, and with the speed of the rotation of the film known the period of combustion could be determined within 5 milliseconds. Fig. 4 shows the tracks of burning particles of bituminous coal burned at a furnace temperature of 806 C. Note the initial short thick portion of the track which represents the combustion of the volatile matter which burned with flame. After the volatile matter had burned, the combustion of the fixed carbon showed a narrow track indicating combustion without luminous flame.

A similar photograph of burning charcoal particles showed the absence of the thick initial portion of the track, there being practically no volatile matter to burn, hence no flame.

Fig. 5. gives a graphical summary of the results of the experiments. Note the pronounced lengthening of the combustion periods with temperatures.

### *Explanation of Temperature vs. Burning Rate*

Why should higher furnace temperatures retard, or speed up, combustion of pulverized fuel?

It has been stated here that the rate at which oxygen makes contact with combustible determines the rate of combustion. If we can find how rising temperature affects the rate of contact making, we can find the answer to the above question. The oxygen is a part of the gaseous mixture in the furnace. The combustible is the solid carbon in the particle of pulverized fuel. The furnace temperature is the temperature of gaseous mixture in the furnace. The temperature of the burning particle of fuel is higher than that of the surrounding gaseous mixture because the heat generated by its combustion raises its temperature above that of the surrounding gases. There is a sharp temperature gradient from the burning particle to the surrounding gases. The following factors come into play with rising furnace temperature.

(*a*) Molecular speed increases as the square root of absolute temperature. This causes the oxygen molecules to hit harder when they make contact with the carbon particle, and thereby may increase the velocity of chemical combination. However, as the rate of chemical combination is already very high and the rate of combustion depends entirely on that of contact making, the harder hitting does not affect the rate of combustion. Molecular speed affects directly the rate of contact making; there-

fore, the rate of contact making should increase as the square root of the absolute temperature.

(*b*) Density of the furnace gases decreases as the absolute temperature rises. There are fewer oxygen molecules in a given volume of furnace gases, and the rate of contact making should decrease in proportion to the density. This decrease should be inversely proportional to the absolute temperature.

(*c*) The viscosity of gases increases with temperature. That is, as the temperature rises resistance to movement of the particle of coal through the gases increases. It requires greater force to move the coal particle out of one place where all the free oxygen has been consumed to another where free oxygen is available; or, the same force causes a slower and shorter movement. The higher viscosity causes the moving coal particles to drag with them the $CO_2$ formed by the combustion, thus reducing the access of free oxygen to the surface of the coal particles.

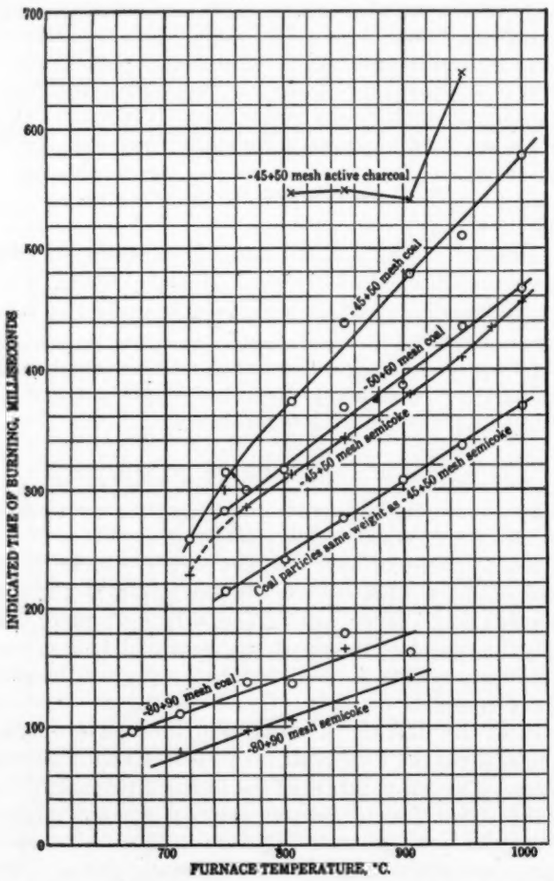



**Fig. 5—Time required for burning powdered fuels of three sizes at various furnace temperatures**

The combined effect of higher molecular speed and lower density of furnace gases caused by the rise of furnace temperature from 700 to 1000 C may decrease the rate of contact making in the ratio of 1.14 to 1, and at the same time the viscosity increases 20 per cent, thus probably decreasing the rate of contact making in the ratio of 1.20 to 1. The combination of these factors would decrease the rate of contact making in the ratio of 1.37 to 1. In other words, the lengthening of the burning period would be about 37 per cent. The observed lengthening of the combustion period was 65 to 70 per cent.

Combustion in the experimental furnace was quicker than it is in a boiler furnace, because the oxygen concentration in the experimental furnace was kept constant at 21 per cent. In a boiler furnace the concentration varies from 21 to about 2 per cent. The average concentration in which the large particles burn probably does not exceed 6 per cent. The rate of contact making and, therefore, the rate of combustion is proportional to the concentration.

There may be a tendency to belittle the value of the results of the experiments because they were made in a small laboratory furnace. However, it seems that the laboratory methods are the best means to acquire exact knowledge. When we wish to study a process like combustion which depends on so many factors, we should vary only one factor at a time and keep the other factors constant. The laboratory apparatus is designed to make this possible. When we attempt to make a similar study with a boiler furnace we cannot control the various factors with any degree of accuracy. The result is that we may credit one factor with the benefit caused by others. Conclusions are often influenced by prejudices rather than sound analytical reasoning.

### *True Causes of Poor Combustion Usually Not Due to Cold Furnaces*

Most difficulties with combustion occur at low ratings and we are in the habit of putting the blame on cold furnaces. The true cause may be too much air with the coal, supplying secondary air too close to the burner and thus interfering with ignition, or supplying both the primary air and secondary air at very low velocity, too low for any effective mixing. Coal delivery pipes, coal nozzles and secondary air ports are designed for the full capacity of the unit. Cross-sectional areas of these parts are made to give sufficiently high velocity for good mixing and good combustion at full rating. The low ratings are left to take care of themselves. It should be borne in mind that the velocity of the coal mixture, and of the secondary air entering the furnace, is a measure of the amount of energy supplied to the furnace for mixing.

At half rating the velocity is about one-half, and the energy one-fourth of that at the full rating; at one-quarter rating the energy is about one-sixteenth. We obtain lower flow by partly closing the dampers in the air ducts and dissipate the energy at the damper; the cross-sectional areas of the coal nozzles and air ports remain unchanged. The worst factor at low rating is that more air is used with the coal than is required for good ignition. We cannot reduce velocity in the coal delivery pipe below a certain minimum, otherwise there would be coal deposition and drifting in the pipe which would result in intermittent coal supply and even plugging of the pipes. With direct firing one must have a certain amount of air flow through the mill which is seldom the right amount for quick ignition. All these factors affect combustion and their effect cannot be nullified by a refractory furnace.

# Improvements in Power Plant of The Gardner-Richardson Co.

By ARTHUR R. HARVEY

Engineering Dept., The Gardner-Richardson Co.

**A new steam-generating unit of 130,000 lb per hr rated capacity at 450 lb pressure takes the place of fourteen 150-lb boilers, and a double-extraction type turbine supplies both the power and process steam demands, the former having previously been met by purchased power and two engine-driven generators. This program of modernization, which was carried out in two steps, effects an excellent heat balance and has been fully justified by the resulting savings in operation. The system of feedwater treatment employed is described in detail.**

THE Gardner-Richardson Company, manufacturer of boxboard and folding paper cartons, has recently installed at its Lockland, Ohio, plant a new boiler of 130,000 lb per hr rated capacity operating at 450 lb pressure, which completes a program of power plant improvement begun several years ago. At the time the improvements were started, the plant had fourteen stoker-fired boilers operating at 150 lb pressure and no superheat. The bulk of the power used in the plant was supplied by two 220-volt direct-current generators driven by Hamilton corliss twin engines. Power was also purchased and used both directly on constant-speed drives at 440 volts, 3 phase, and to some extent as 220-volt direct current through the operation of a large motor-generator set. The steam balance was rather poor, there being considerable exhaust steam from the engines which was not used for process work.

After a study had been made of the power and steam requirements, it was decided to install a bleeder-type turbine and a high-pressure boiler to bring about a better steam balance and to secure the economy of a steam-generating unit of modern design.

In order to provide immediately for increased power requirements, and still break up the installation into two steps, the turbine was installed first. The machine selected was a General Electric double-extraction type designed for a throttle pressure of 400 lb, 100 deg superheat, with provision for extraction at 150 lb and also at 40 lb pressure. This permitted initial operation of the turbine on the 150-lb steam from the old boilers which also carried the load of the reciprocating-engine-driven generators. This arrangement likewise provides for operation on the old boiler equipment as required during periodic inspection or repairs to the new equipment. The generator is rated at 4000 kw, 440 volts, 3 phase, 60 cycles at 80 per cent power factor and has a direct-connected exciter. Excitation voltage of 220 was chosen to correspond with the existing direct-current voltage.

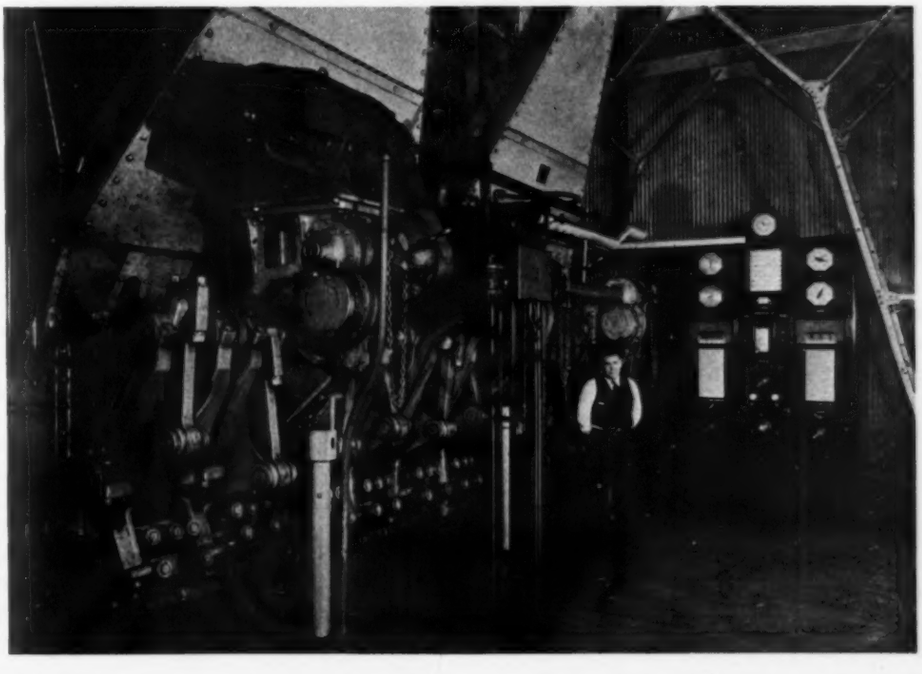


Fig. 1—Firing aisle and control board

The switchboard equipment is of Westinghouse design and includes panels for the additional power required. Sufficient constant-speed direct-current motor drives were converted to alternating current to reduce the load on the engines and to reduce the amount of exhaust steam not being used in process work. The balance of 40-lb steam required for process work is extracted from the turbine. By taking on all the alternating-current power formerly purchased and by improving the steam balance, in addition to providing for the further increased power load, this first step involving the turbine installation has "paid its way."

### *Second Step of Program Completed*

Recently, the starting up of a new Combustion Engineering multiple-circulation bent-tube boiler has completed the program of improvements. This unit has 13,115 sq ft of heating surface in the boiler proper, and 512 sq ft of heating surface in the water-cooled bridgewall, the lower portion of these tubes adjacent to the clinker grinder pit being equipped with C-E integral blocks. The boiler has a rated capacity of 130,000 lb of steam per hour continuously and 150,000 lb maximum. This capacity might be further increased if required in the future by the addition of side water walls. An Elesco superheater of the intertube convection type raises the steam temperature 165 deg or to a total temperature of 625 F. The gases upon leaving the boiler pass through a 3430-sq ft Elesco fintube economizer which raises the feedwater temperature from 210 to approximately 285 F. Upon leaving the economizer the gases pass through a C-E plate-type air preheater which raises the air temperature to approximately 300 F.

The boiler is fired by a 12-retort Taylor stoker having a projected grate area of 365 sq ft. This is normally driven by a variable-speed direct-current motor under automatic control, but it may also be driven by a Terry steam turbine.

The forced- and induced-draft fans of American Blower design are driven by constant-speed alternating-current motors, the speed of the fans being controlled by hydraulic couplings which are connected to the automatic combustion control system. The latter is of the Smoot oil-operating type consisting of a master controller connected to the main steam header and actuating a regulator which controls the hydraulic coupling on the induced-draft fan drive and another regulator operating the rheostat of the stoker-driving motor. A separate furnace draft regulator actuates the forced-draft fan damper.

The combustion control panel and equipment as illustrated were furnished by the Republic Flow Meters Company and consist of a 7-unit draft gage, steam flow and $CO_2$ indicators, steam-flow integrator, and steam and feedwater pressure gages. There are also two strip chart recorders which make a continuous record of the gas temperatures leaving the boiler, economizer and air heater, of the water temperatures entering and leaving the economizer, of the air temperatures entering and leaving the air heater, percentage of $CO_2$, steam pressure, total steam temperature and furnace draft. The $CO_2$ per cent can be set at any predetermined point by means of needle valves on the panel which control the air and fuel regulators.

Coal handling equipment of Fairfield design consists of a track hopper from which the coal is delivered by means of an automatic skip hoist to a 200-ton overhead bunker, as shown in the exterior view of the boiler house. A Richardson automatic coal scale records the amount of coal delivered from the bunkers through the downspouts to the stoker hopper.

Ash is discharged from the stoker by means of 18-in. double crusher rolls to an ash hopper from which a "Nu-veyor" system delivers it to an overhead tiled bin in the rear of the plant.

### *Feedwater Treatment*

Feedwater to the boiler is treated in a Scaife cold-process, intermittent lime-and-soda softener with three

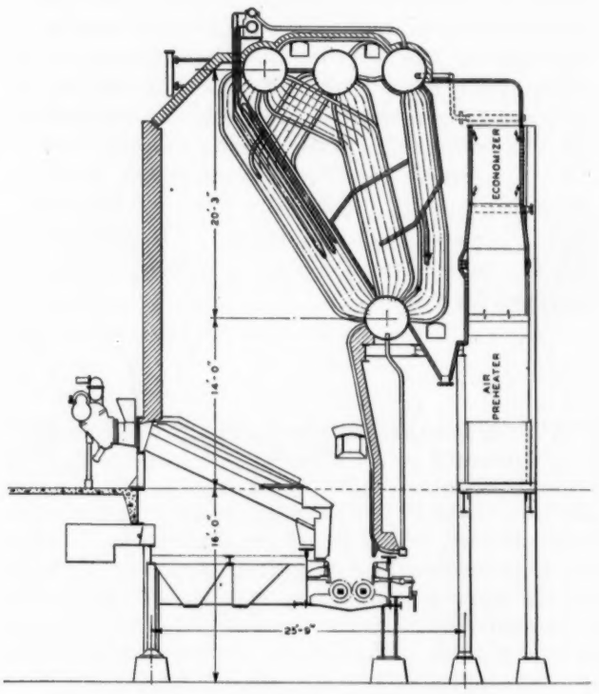



**Fig. 2—Section through steam-generating unit**

32,000-gallon treating tanks and two sand gravity filters. The filters discharge to a storage well, from which booster pumps deliver it to the Cochrane deaerating feedwater heater.

While raw water from the reservoir is being pumped into the treating tank, in which a rotating agitator is in operation, a mixture of slaked lime and water from a small mixing tank in the softening plant is pumped in by a steam siphon. The slaked lime reacts with iron, aluminum, calcium and magnesium salts, forming insoluble hydroxides and carbonates. One hour is allowed for the lime to react on the water. A mixture of water and soda ash with some sodium aluminate, the latter acting as coagulant and softener, is then pumped from the small mixing tank into the treating tank. The sodium carbonate precipitates the calcium sulphate and the sodium aluminate precipitates some of the magnesium. A half hour after adding the soda ash, the agitator is shut down and the precipitates, aided by the coagulant, settle to the bottom of the tank as a sludge. The clear water above the sludge is drawn off through a floating pipe and filtered through a sand filter, which removes any fine material that has not settled out in the sludge. The amount

of lime and soda ash used in this process is predetermined by chemical tests on each tank of raw water. An average tank of 31,000 gallons of the raw water contains 120 lb of scale-forming ingredients, while after passing through the cold process, this has been reduced to less than 3 lb. Leaving the filters of the lime-soda process, the water has a hardness of not over 1 grain per gallon, this hardness being due largely to carbonates of calcium and magnesium.

The water is pumped from the lime-soda process to the hot or phosphate process. This is a continuous treatment where the water is heated to about 215 F. The continuous addition of a solution of di-sodium phosphate

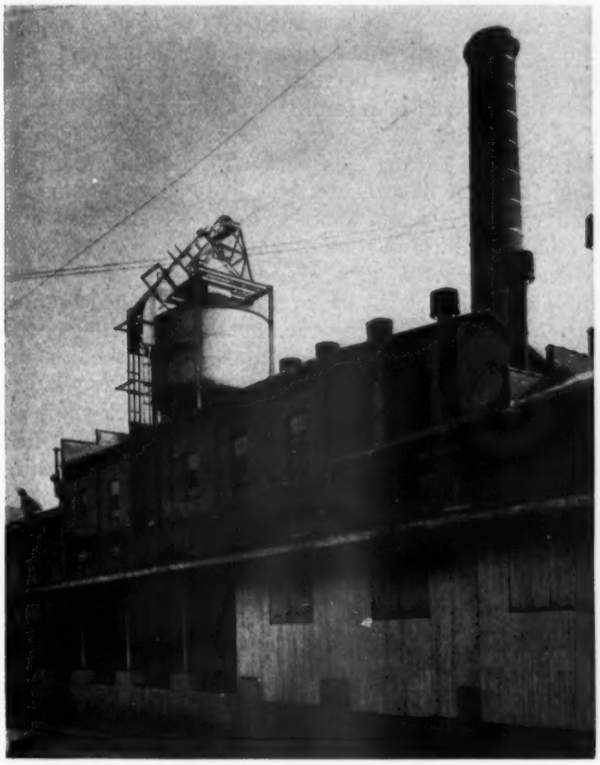


**Fig. 3—Coal is handled by an automatic skip hoist to a 200-ton overhead bunker**

precipitates what little scale-forming ingredients remain in the water. The precipitates settle quickly, leaving but a trace of suspended material to be clarified by passing through a filter, and on into the boiler. The filter bed used for this is of magnetite, as hot alkaline water would dissolve and carry silica into the boiler if a sand filter bed were used. Water passing to the boiler has been freed from scale-forming ingredients which have been replaced by salts of sodium. In order to prevent the forming of hard substances as the water is evaporated from the concentration of these salts, "Nalco No. 8" is added; this maintains the concentrates in a soft fluffy condition, which can be readily blown down. To remove any oil that may have got into the system an oil-removing material is added. Hourly checks are made of the boiler concentration by electrochemical means and the opening and closing of the calibrated blow-off valve is determined by these tests.

In order to economize on steam and softened water, every means possible is used to return all condensed steam to the boiler.

The power piping is of welded construction.

This new boiler unit has now been in operation for about a year. At the present time the load averages about 130,000 lb per hr during the week, and about 40,000 lb per hr over week-ends. On Sundays when the high-pressure turbine is usually shut down, the new boiler feeds the old 150-lb system through a master control reducing valve and a desuperheater which reduces the total temperature of the steam from 600 to 465 F.

These power plant improvements have justified themselves by the savings brought about by substituting a boiler operating at an average monthly efficiency of 84.3 per cent as compared with the 70 per cent previously obtained on the old boiler equipment which it replaced. The improvement also effects additional savings by reducing the amount of steam required to operate the mill.

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## Test Alumni Celebrate

The annual reunion of General Electric Test Alumni Association, composed of all the engineers who have taken the G. E. test course since the 1880's, was held at the Mohawk Club, Schenectady, on December 9. A feature of the program was the presentation to the Edison Club of an oil portrait of A. L. Rohrer, formerly in charge of the test personnel but retired since 1914. The presentation was made by R. C. Muir, G. E. vice president, and accepted by C. D. Greentree, president of the Club. J. B. Crane, of Combustion Engineering Company, who was the first president of the Edison Club, told of its formation and early activities. Other speakers included past presidents, F. W. Peters, M. O. Troy and K. A. Pauly; as well as C. F. Pittman, L. B. Bonnett, C. L. Proctor and J. S. Wise, vice presidents of the Test Alumni. The program was broadcast by short wave to groups of more than 7000 former G. E. test men scattered all over the world.

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## Heads United Engineering Trustees

D. Robert Yarnall, chief engineer of the Yarnall-Waring Company of Philadelphia, has been elected president of United Engineering Trustees, joint agency of the four Founder societies of civil, mining and metallurgical, mechanical and electrical engineers. Mr. Yarnall succeeds George L. Knight, vice president of the Brooklyn Edison Company.

Albert Roberts, of the North American Corporation, and Henry A. Lardner, of J. G. White Engineering Corporation, were chosen vice presidents, and H. R. Woodrow, vice president of the Consolidated Edison Company of New York, becomes treasurer to succeed Mr. Roberts.

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**The Executive Committee of the Fuels Division, A.S.M.E.,** has appointed a subcommittee, consisting of Thomas A. Marsh and K. M. Irwin, to cooperate with the Consumers' Counsel in considering activities of the National Bituminous Coal Commission.

# Preliminary Operation of High-Pressure Units

**At the Power Panel Discussion during the A. S. M. E. Annual Meeting on December 8, several of the speakers described the procedure employed in putting their high-pressure topping units into initial operation. Each of the steam-generating units referred to in the following are fired with pulverized coal and have slagging-bottom furnaces. In three of the cases mentioned gas is employed to bring the unit up to partial pressure and the fourth uses oil for this purpose.**

### *Starting the Units at Waterside*

AT Waterside Station, New York, according to W. E. Caldwell, of the Consolidated Edison Company, the 500,000-lb per hr, 1200-lb pressure steam-generating units were brought up from cold condition to around 200 to 300 lb pressure by city gas from the electrically-ignited pilot burners. This steam pressure is sufficient to start the 50,000-kw high-pressure turbine-generator rolling. After about half an hour the pressure is built up to around 500 lb by intermittent coal firing, during which the speed of the turbine is slowly increased to 2800 rpm. The steam admission valves on the feed-heating turbine are then closed slowly to bring the back pressure to 200 lb. The 200-lb check valves then open and the boiler pressure is increased to 600 lb. Synchronous speed is reached with a steam pressure of about 650 lb at which the machine is synchronized and the steam pressure increased to the normal working level.

The use of gas for starting the boiler permits gradual heating of the surfaces before introducing the pulverized coal. Also, the direct-connected feed-heating turbine, which is a special feature of this installation, aids in starting, since it exhausts at atmospheric pressure and delivers a substantial amount of torque as the back pressure is being built up at the exhaust of the main unit.

The boilers have furnaces of the continuous slag-drip type and in starting them for the first time stoker clinkers were spread over the water-cooled furnace floor for protection. As the rating increased this slag became fluid.

### *Procedure at Fisk Street Station*

Preliminary operation of one of the two 375,000-lb per hr, 1275-lb boilers and the high-pressure turbine at Fisk Street Station, Chicago, was described by A. E. Grunert, of the Commonwealth Edison Company.

After the usual trying out of the auxiliary equipment and interlocking system, the boiler was boiled out at 500 lb pressure with a caustic solution for three days. It was then drained and refilled, brought up and put on the line for the first time. The starting procedure adopted consisted essentially of intermittent firing at such intervals that the full header pressure was developed in about four hours. During this period the damper in the gas duct from the superheater was kept partially closed so that most of the hot gases passed over the economizer section, the lower portion of which is tied into the boiler, so as to provide recirculation through this section. Circulation in the superheater was maintained by opening the bleeder valve on the superheater outlet header.

The turbine was brought up to speed for the first time by warming up with low-pressure steam, admitted through the bypass around the exhaust check valve and out through the high-pressure gland leak-off. During this warming-up period of about four hours the drains were opened and the spindle continuously rotated by the turning gear. After the turbine had been thoroughly heated to the exhaust temperature the bypass around the check valve was closed and the throttle opened, admitting high-pressure steam, thus bringing the unit up to speed in about one hour.

### *Reheat Boiler at Northeast Station*

J. A. Keeth, of the Kansas City Power & Light Company, spoke of the procedure followed in initially starting the 300,000-lb per hr, 1350-lb pressure reheat boiler at the Northeast Station.

The preliminary steaming operation with this unit was the boiling out of the boiler, superheater and economizer. Filling was accomplished through the walls and superheater drain connections in order to overcome air pockets. A small tank containing tri-sodium phosphate was mounted on the top of the boiler with connections to the drum, economizer and superheater headers. On the first boiling out, 200 lb of phosphate was put through the drum and 50 lb each in the economizer and superheater. The boiler was fired at a low rating by means of the gas pilot flames for a period of three days during which the water was allowed to expand and overflow out of the drum vent. Steam from the station reheater header was bled through the new reheater element to atmosphere for cleaning it.

The operation was repeated to remove some residual oil and grease but this time the vent was closed, the level dropped and the pressure raised to 1000 lb to permit higher temperature and a thorough blowing down.

After inspection showed the surfaces to be clean,

the boiler was refilled with condensate to the working level and fired slowly with two of the main gas burners. About six hours were taken, on this initial operation, to bring the boiler up to full pressure after which the safety valves were checked and set.

During the period required for checking and setting these valves, the boiler was held at 70,000 lb evaporation by means of two gas burners. The steam was taken out of a bypass connection on the boiler side of the superheater non-return valve and put directly into the reheater inlet. The desuperheating was accomplished by admitting into the reheater along with this steam sufficient low-temperature steam from the station reheater inlet header. The steam thus passed through the new reheater flowed, directly after superheating to 700 F, into the station low-pressure header. This arrangement afforded an ideal method of protecting the superheater and reheater during the preliminary operations at pressures below that of the station high-pressure header. When the safety valves had been set, the boiler was put on the plant high-pressure header and the bypass around the non-return valve closed. A portion of the exhaust from the present high-pressure turbine was put through the reheater of the new boiler. The rating was then raised to 100,000 lb per hr by lighting two additional gas burners so as to distribute the fire uniformly and to serve as ignitors for the pulverized coal.

After operating in this manner for a short period one mill was started and a coal burner in each corner ignited from the gas flame. As soon as air adjustments had been made the quantity of gas was reduced and the coal feed increased to produce a total evaporation of about 150,000 lb per hr. The unit has a continuous slagging bottom and slag became fluid at this rating. On the second trial run the boiler was brought up to pressure with gas in about four hours, and operation with coal alone at 200,000 lb rating was continued during the day and with gas at half this capacity during the night.

### *Twelfth Street Station, Richmond Va.*

J. A. Reich, of the Virginia Electric & Power Company, told of the starting of the 450,000-lb per hr, 900-lb pressure, pulverized-coal-fired unit at the Twelfth Street Station in Richmond, Va.

Following a brief trial with bottled propane gas and automatic high-voltage spark ignition for lighting off, which was not entirely satisfactory, an oil ignition system of conventional design was adopted for this purpose. This employs mechanical atomizing torches, inserted between each of the upper and lower pairs of coal nozzles. The combined capacity of these oil torches is sufficient to produce about 30 per cent capacity or an evaporation of 130,000 lb of steam per hour.

The usual procedure in starting is to keep the oil on for about an hour until the steam pressure has reached around 600 lb, after which the coal feed is increased and the oil cut down. The unit is brought up to 850 lb, the operating pressure, in about two hours. If a quicker start is desired, the mill is put on at half its capacity at the end of 10 min and the oil cut off at the end of 20 min. After the flow of slag on the furnace bottom has been started the rating can be dropped to 225,000 lb of steam per hour and satisfactory tapping conditions maintained.


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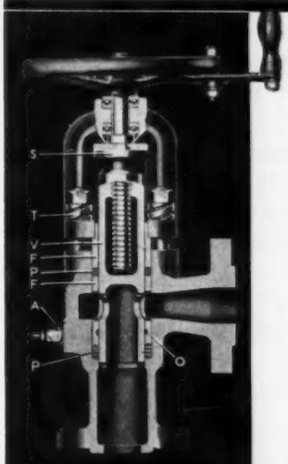


Yarway Seatless Blow-off Valve. Operation: After Valve is closed, shoulder S on plunger V contacts with upper follower gland F, forcing it down into body and compressing packing P above and below port. Annular groove O connects with Alemite fitting A for lubricating plunger and packing. Yoke springs T maintain continuous pressure through follower gland F on packing rings P.

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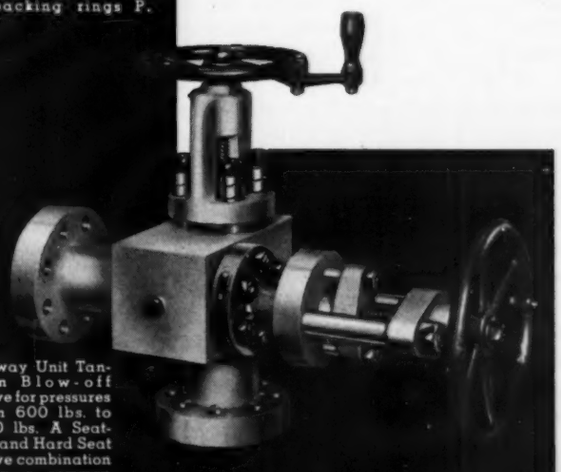

Yarway Unit Tandem Blow-off Valve for pressures from 600 lbs. to 1500 lbs. A Seatless and Hard Seat Valve combination using a common forged steel body.

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# STEAM TURBINE TRENDS

**A composite digest of the E.E.I. Prime Movers Committee Report and reviews prepared by certain turbine manufacturers shows that, with the exception of one condensing unit on order for 2300 lb pressure, 940 F steam temperature, there has been no tendency to exceed the established 1200-lb throttle pressure; although the number of units for such pressure has increased greatly both in large and smaller sizes. Higher steam temperatures are being employed and 3600 rpm machines with hydrogen cooling are on the increase. The best turbine performance noted is that of the 80,000-kw, 1200-lb machine at Port Washington Station which on test showed a heat consumption of 8580 Btu per kwhr.**

THE recent report of the Prime Movers Committee on "Turbines" shows that seventy-four machines for central station service, in sizes above 10,000 kw, have been ordered since late in 1935. These represent an aggregate capacity of 2,282,500 kw. Making allowance for the lapse in time between the collection of the data and the preparation and publication of the report, present figures will somewhat exceed those given.

Superposed turbines, comprising twenty units, account for 625,000 kw, or 27.4 per cent, of the new capacity. Of these, seventeen are for steam pressures of 1200 lb per sq in. or over, and three for pressures under 1200 lb.

Of the seventy-four machines covered in the report, more than half were for operation at 3600 rpm and represented a capacity of 1,217,500 kw.

On the basis of a pressure of 1200 lb and over, including both topping units and those operating condensing, there were twenty with an aggregate capacity of 687,500 kw, or 30.1 per cent, of the total capacity added.

For steam temperatures ranging from 800 to 925 F there were fifty machines comprising 1,652,500 kw capacity, or 72.4 per cent of the total. The greater portion of this capacity is designed for operation at 900 F total steam temperature, or over.

Operating data for the year 1936 are given for three hundred and fifteen turbines, of which seventeen are high-pressure units. The average service demand availability of the latter was 89.25 per cent.

Outstanding in the line of performance was the remarkably low heat consumption of the 80,000-kw, 1200-lb Allis-Chalmers machine at the Port Washington Station of the Milwaukee Electric Railway and Light Company. On test at 60,000 kw and a throttle temperature of 832 F, with reheat at 814 F and a condenser vacuum of 1 in. Hg, the corrected heat consumption was 8580 Btu per kwhr. The average water rate, measured at the throttle, was 7.589 lb per kwhr.

Supplementary to the foregoing are the statements released at the end of 1937 by the General Electric Company and by the Westinghouse Electric & Manufacturing Company concerning trends as indicated by units sold during the year.

The former lists sixteen hydrogen-cooled units, representing a total capacity of more than a million kva, as either already installed or under construction. Outstanding among these are the third 110,000-kw, 1200-lb, 900-F vertical compound unit for the Ford Motor Company and the 150,000-kw, 1200-lb, 825-F triple, tandem-compound machine at the State Line Station near Chicago. The generator of the latter unit was originally shipped as an air-cooled machine but was later adapted to hydrogen cooling, which resulted in a gain of 21,200 kva and a reduction in losses of 878 kw.

Mention is made of the 2300-lb per sq in., 940-F total steam temperature unit on order for the Twin Branch Station of the Indiana & Michigan Electric Company. This will consist of a 22,500-kw high-pressure turbine that will be cross-compounded with a new 45,000-kw, 385-lb low-pressure unit. Later, when the present 600-lb boilers at this station are to be replaced and additional 2300-lb topping turbines are installed, the high-pressure units will operate superposed on a 400-lb plant.

Among a number of other large units mentioned, are two 75,000-kw single-casing turbines to operate at 815 lb, 900 F and 1 in. back pressure at the Delray Station in Detroit; the second and third 60,000-kw single-casing, 600-lb, 825 F, 1800-rpm units for the Conners Creek Station; a 75,000-kw, 315-lb, 725-F, 1800-rpm machine for the Cahokia Station in St. Louis; a 50,000-kw, 375-lb, 700-F machine for the Cleveland Electric Illuminating Company; the 40,000-kw, 1250-lb, 925-F, 3600-rpm hydrogen-cooled unit recently placed in service at the Logan Station of the Appalachian Electric Power Company; and the 25,000-kw, 3600-rpm, 1200-lb, 925-F topping unit at the Rivesville Station.

Three units of compact tandem-compound double-flow design with fabricated exhaust hoods were installed during the year.

The continuing upward trend in initial pressures and temperatures of smaller turbine-generators is indicated by several machines under construction. One for the Dow Chemical Company is rated at 7500 kw, 1250 lb, 825 F and 385 lb exhaust. The Tampa Electric Company has ordered a 6000-kw unit to operate at 835 lb, 800 F and 210 lb exhaust; and the Toledo Edison Company will install a 5000-kw turbine to operate at 825 lb, 825 F and 225 lb exhaust.

As in the case of turbine-generators the trend in mechanical-drive turbines, such as for driving boiler feed pumps, is toward high pressures and high temperatures.

The following is taken from the Westinghouse statement, signed by E. R. Kauffman of the Turbine Division.

*Central Station Turbines*

The classification of prime mover units (7500 kw capacity and larger) under construction during the year shows some interesting trends.

| Type | No. | Capacity, Kw | Per Cent of Capacity |
|---|---|---|---|
| Condensing | 19 | 525,000 | 69 |
| Non-condensing | 7 | 237,500 | 31 |
| Speed | | | |
| 1800 (1500) rpm | 7 | 250,000 | 33 |
| 3600 rpm | 19 | 512,500 | 67 |
| Inlet Temperature | | | |
| Up to 750 F | 10 | 232,500 | 30 |
| 751 to 850 F | 8 | 247,500 | 33 |
| 851 and higher | 8 | 282,500 | 37 |
| Inlet Pressure | | | |
| Up to 450 lb | 9 | 220,000 | 29 |
| 451 to 650 lb | 6 | 155,000 | 20 |
| 651 lb and higher | 11 | 387,500 | 51 |

The most significant facts shown by the above are:

(*a*) 31 per cent of the total capacity will operate non-condensing

(*b*) 67 per cent will operate at 3600 rpm

(*c*) 37 per cent will operate with inlet temperatures above 850 F

(*d*) 51 per cent will operate with inlet pressures above 650 lb per sq in. gage.

There has been no advance in the maximum capacity of individual units, and in fact, there are no units under construction at the present time equal in size to the largest units built six or seven years ago. While the application of 50,000-kw superposed units places comparatively large capacities under control of single turbines, the recent orders for condensing machines indicate a trend toward units of moderate size.

*Turbines for Auxiliaries*

Turbines which have hitherto been considered as industrial type machines are finding applications in the central station industry in the form of auxiliary drives, particularly as boiler feed-pump drives in connection with superposed turbine installations. When old plants are rehabilitated by superposition, there is usually a problem of obtaining adequate feedwater heating. Boiler feed pump drives of the larger of these installations may require as much as 1500 to 2000 hp.

*Small and Moderate Capacity Turbines*

In the field of the small and moderate capacity turbines, many applications involve both power and process steam requirements. Due to the diversity of conditions to be met, turbines for such applications must necessarily be built to order. In this field, a classification of eighty-four units (of 500 kw capacity and larger) with a total capacity of 192,000 kw shows the following trend in type of application:

| | No. | Distribution of Capacity | Per Cent of Capacity |
|---|---|---|---|
| Condensing | 8 | 21,400 | 11 |
| Non-condensing | 33 | 50,725 | 26 |
| Condensing extraction | 37 | 103,250 | 54 |
| Non-condensing extraction | 6 | 16,625 | 9 |


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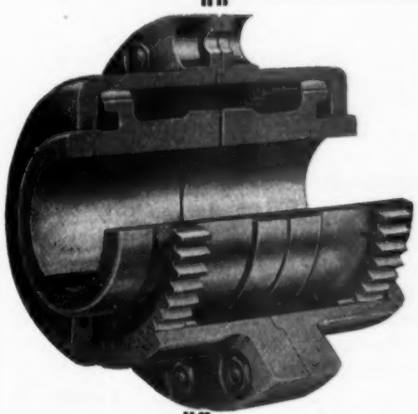

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**Engineering executives purchase equipment on demonstrated performance. That Vulcan Soot Blowers are on the preferred list of engineers who buy because of demonstrated lowest maintenance sound engineering and the ruggedest construction ever built into Soot Blowers, is evidenced by the following partial list of representative contracts installed or sold in 1937.**

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Ames, City of.....Ames, Iowa
Atlantic Refining Co.....Atreco, Texas
Baltimore Transit Co.....Baltimore, Md.
Bethlehem Steel Co.....Sparrows Point, Md.
Chain Belt Company.....Milwaukee, Wis.
Columbia Enameling & Stamping Co..Terre Haute, Ind.
Container Corporation.....Carthage, Ind.
Continental Diamond Fibre Co.....Newark, N. J.
Crosley Radio Corporation.....Cincinnati, Ohio
Eldora Gold Mines.....Port Hope, Ontario
Elgin, Joliet & Eastern R. R. Co.....Gary, Ind.
Formica Insulating Co.....Cincinnati, Ohio
Globe Steel Tubes Co.....Milwaukee, Wis.
Hamilton Coke & Iron Co.....Hamilton, Ohio
Helwig Silk Dyeing Co.....Philadelphia, Pa.
Hudepohl Brewing Co.....Cincinnati, Ohio
Jose Arechabala Sociedad.....Cardenas, Cuba
Kaukau Sugar Co.....Honolulu, Hawaii
Kendall Refining Co.....Bradford, Pa.
Keystone Public Service Co.....Oil City, Pa.
Latonia Refining Co.....Latonia, Ky.
Lehigh Portland Cement Co.....Oglesby, Ill.
McAndrews & Forbes.....Camden, N. J.
M Street Heating Plant.....Washington, D. C.
MacSim Bar Paper Co.....Otsego, Mich.
Mendocino State Hospital.....Mendocino, Calif.
Metropolitan Edison Co.....Reading, Pa.
Municipal Power Plant.....Rochester, Minn.
N. Y. State Electric & Gas Co.....Dresden, N. Y.
Ohio Power Co.....Windsor, W. Va.
Pennsylvania Electric Co.....Sewart, Pa.
Ralston Purina Company.....Battle Creek, Mich.
Republic Oil & Refining Co.....Texas City, Texas
Republic Steel Co.....Thomas, Ala.
Rochester & Pittsburgh Coal Co.....Lucerne, Pa.
Schervier Hospital.....New York City
Sherwood Refining Co.....Warren, Pa.
Sloan Blabon Co.....Philadelphia, Pa.
A. E. Staley Mfg. Co.....Decatur, Ill.
Thilmany Pulp & Paper Co.....Kaukauna, Wis.
Tide Water Power Co.....Wilmington, N. C.
Timken Roller Bearing Co.....Columbus, Ohio
United Refining Co.....Warren, Pa.
U. S. Military Academy.....West Point, N. Y.
Vacuum Oil Co.....Paulsboro, N. J.
Village of Hinsdale.....Hinsdale, Ill.
Washington Gas Light Co.....Washington, D. C.
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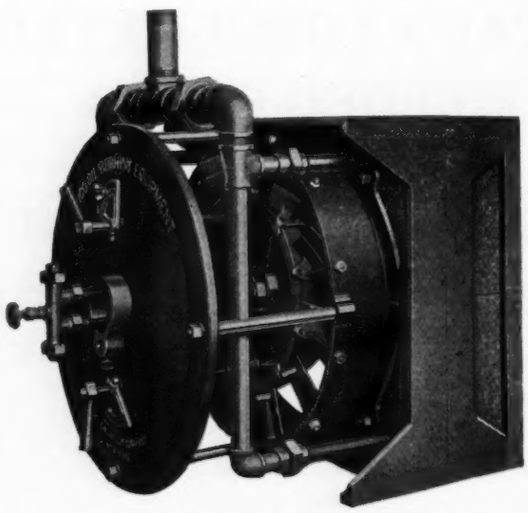
## Enco Burners



*Assembly of Type W Gas-Oil Burner Unit*

Enco Oil Burner Units are made with attachments to burn various types of gas fuels.

Fine jets of gas are driven across the stream of air passing through the registers. This provides turbulence and an intimate mixture of gas and air. Practically flameless combustion results with correspondingly high efficiency.

The illustration shows the assembly of the Type W unit. It will be noted that the wall box not only secures the unit in the furnace wall, but also supports the overhead brickwork; in addition, it serves as a protection from the stresses developed in the furnace when hot.

The unit shown has a capacity of 275 H.P. natural draft and 500 H.P. when mechanical draft is applied.

With these units, instant change from gas to oil can be made without affecting the output of the boiler.

*Write for Bulletin OB-37*

**THE ENGINEER COMPANY**

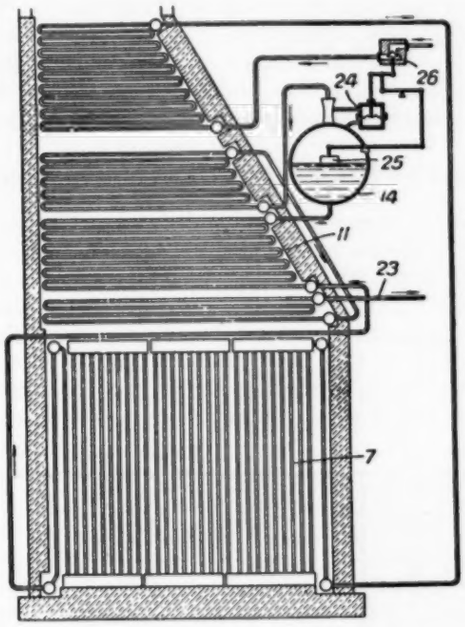
17 Battery Place New York

# STEAM ENGINEERING ABROAD

## As reported in the foreign technical press

### Drum on "Once-Through" Boiler

Due to lack of water-storage capacity in the conventional "once-through" type of forced-circulation boiler very close control is necessary in order to adjust the steaming rate to the steam demand. Because of this, an interesting modification in design has recently been covered in a patent issued to Siemens-Schuckertwerke




**Drum applied to Benson boiler**

Akt.-Ges., builder of the Benson boiler. This involves the addition of a drum in the circuit to assist in regulating the ratio of the feedwater to the fuel supply, to accommodate variations in load, by changes in the water level in the drum.

Referring to the accompanying sketch, reproduced from the November issue of *The Fuel Economist*, when operating at steady load dry saturated steam enters the drum and comes in contact with the feedwater. Steam from the upper part of the drum passes to the superheating coils. The feed valve, *26*, is controlled by float, *25*, in the drum, and by a regulating device, *24*, the latter operated by the pressure varying in accordance with the steam demand. That is, a sudden increase in steam demand will be accompanied by a drop in steam pressure which will cause the control to increase the firing rate of the fuel. At the same time the increased steam demand will cause the level in the drum to fall and the float which actuates the feed valve, *26*, will cause the feed to be increased. Also, the regulator, *26*, will cause further opening of the feed valve, as required. Conversely, if wet steam enters the drum the feed valve is partially closed.

In a modification of this scheme, the steam enters the drum through a pipe coil arranged in the water space and opening into the steam space, and part of the steam may flow directly from the steam-generating sections under the control of a valve operated in dependence upon the difference in pressure at the inlet and outlet of the drum.

Although not so stated in the patent it is likely that a further reason for the addition of a drum is to facilitate blowing down accumulations of solids that form in the steaming circuit.

### Year's Performance at Fulham

*Engineering and Boiler House Review* (London) for December contains some figures on the first twelve months of commercial operation of the new Fulham Power Station up to October 31, 1937. This station[1], which is laid out as a base load plant of 300,000 kw ultimate capacity, now has 120,000 kw in two 60,000-kw turbine-generators supplied with steam at 625 lb pressure, 850 F, by six 260,000 lb per hr stoker-fired boilers equipped with both economizers and air heaters.

With 12,815 Btu coal and a station load factor of 48.44 per cent the performance was 0.9466 lb of coal per killowatt-hour, on the basis of units generated. The corresponding thermal efficiency was 28.27 per cent. Attention is called to the fact that this includes the period of tuning up and adjustments incident to the first few months of operation of a new plant, and further improvement in these figures is anticipated. The total units of electricity generated during the twelve months was 557,609,950 kwhr. The first turbine-generator operated 82.7 per cent of the time and the second, which went into commission some weeks later, operated 76.5 per cent of the time.

### Nickel Alloys for Valve Parts

Nickel alloys for valves, resistant to abrasion and oxidation at high steam temperatures and having suitable coefficients of expansion, are discussed in the December issue of *Engineering and Boiler House Review* (London).

Satisfactory alloys of this character for valve seats and faces have, in general, a base of nickel-copper alloy to which appreciable percentages of various hardening elements, particularly tin and sometimes silicon or chromium, are added. The composition varies with the service conditions and the nickel content may range from 20 to 70 per cent. Care must be taken to avoid a wide

[1] For a description see COMBUSTION, November 1934.

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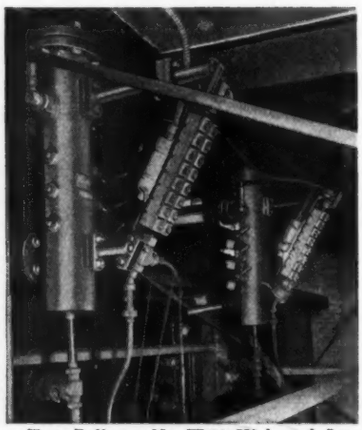

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difference in the coefficient of expansion of the alloy and that of the material in which it is housed.

It has been found that a typical hardened nickel-copper alloy will have a tensile strength of 70,000 to 80,000 lb per sq in. at normal temperature, falling off to about 56,000 lb per sq in. at 800 F. Such an alloy, therefore, is as strong at 800 F as is mild steel at normal temperature, and at 1100 F it is stronger than bronze at normal temperature.

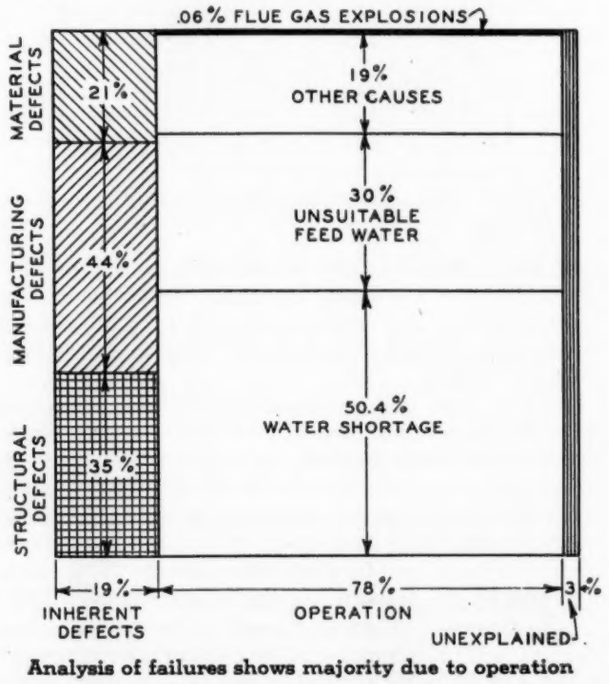
The following tabulation gives the properties of a typical nickel-copper-tin alloy, containing 50 per cent nickel, 40 per cent copper and 10 per cent tin, as used for valve seats at elevated temperatures:

| Temperature Deg F | Maximum Stress I.b per Sq In. | Elongation in 2 In. Per Cent |
|---|---|---|
| Room | 76,000 | 0.5 |
| 750 | 65,000 | 1.0 |
| 900 | 54,000 | 1.0 |
| 1000 | 45,000 | 1.0 |
| 1100 | 38,400 | 1.0 |

That these alloys are especially resistant to abrasion and do not seize is probably accounted for by their "bearing" type of structure, consisting of hard particles embedded in a softer matrix. However, as indicated by their relatively low elongation, they are not readily workable and are therefore available only in cast form.

## Causes of Boiler Failures in Germany

That the majority of boiler failures are caused by improper operation is indicated by the 1936–1937 report of the Prussian Boiler Supervising Association covering two hundred twenty-eight cases. Of these, three were boiler explosions; one was a flue gas explosion; thirty-one resulted in sudden and complete outage of the unit; one hundred and sixty-nine, while not causing complete outage, did result in immediate removal from service;




**Analysis of failures shows majority due to operation**

and the remainder were of a less serious nature. Seventy-five per cent of all the cases reported occurred with fire-tube or firebox boilers. The following tabulation indicates the types of boilers and the character of the damages:

CLASSIFICATION OF FAILURES

| Type | Blisters or Bagging | Bending Fractures | Cracks in Plate | Rivet Hole Cracks | Corrosion | Tube Fractures | Other Damage | Total |
|---|---|---|---|---|---|---|---|---|
| Fire tube | 74 | 9 | 6 | 1 | 10 | .. | 5 | 105 |
| Firebox | 25 | 6 | 4 | 1 | 20 | .. | 10 | 66 |
| Straight tube (water tube) | .. | .. | .. | .. | .. | 8 | 2 | 10 |
| Bent tube (water tube) | .. | .. | 1 | 15 | .. | 3 | 2 | 21 |
| Marine | 1 | .. | 2 | .. | 1 | .. | 1 | 5 |
| Others | 5 | .. | 3 | .. | 3 | 6 | 4 | 21 |
| | 105 | 15 | 16 | 17 | 34 | 17 | 24 | 228 |

The accompanying diagram, reproduced and translated from *Archiv für Wärmewirtschaft und Dampfkesselwesen* of October 1937, visualizes the causes which led to the failures. From this it will be seen that over 78 per cent were attributable to operation and of these over 80 per cent were due to improper feedwater or to water shortage.

## High Heat Release Attained with Lancashire Boiler

Tests of pulverized-coal firing of a Lancashire boiler were described in a paper by T. F. Hurley and R. Cook which was presented before the Institute of Fuel (London) on December 9, and reported in the *Electrical Review* of December 17. These tests formed part of the extensive fuel research program that is now being carried out by the Department of Scientific and Industrial Research.

The boiler was of small rated capacity—5000 lb per hr—and was fired from a storage system. Runs were made with two different types of burners, one of the grid type and the other of multi-jet design. Because of the low ratio of furnace volume to the total heating service in this type of internally-fired boiler, which is used extensively in England, high rates of heat liberation were obtained. These ran as high as 68,900 Btu per cu ft, considering the whole furnace tube as the combustion chamber. The total steam temperature maintained on these tests was 680 F.

A higher maximum rating, namely, 247 per cent, was obtained with the multi-jet burner than with the grid-type burner which attained only 235 per cent. With the former a gross thermal efficiency of 80 per cent was reached at rated capacity. This was considered excellent in view of the fact that neither an economizer nor an air heater was provided; hence the flue gas temperatures leaving the boiler were relatively high. At this capacity the efficiency with the grid burner was 75 per cent. The better performance with the multi-jet burner was attributed to the more intimate mixing of the fuel and air due to the turbulence set up in the furnace.

However, at loads in excess of 11,000 lb of steam per hour, the grid-type burner showed up better and the efficiency with the multi-jet burner was only 60 per cent. An explanation of this was not given.

The $CO_2$ was maintained at 14.5 to 15.5 per cent and with the low excess air necessary to maintain this percentage of $CO_2$, skill was required to prevent slag accumulations. The coal burned averaged 35 per cent volatile matter and ranged in ash content from 4.1 to 8.1 per cent.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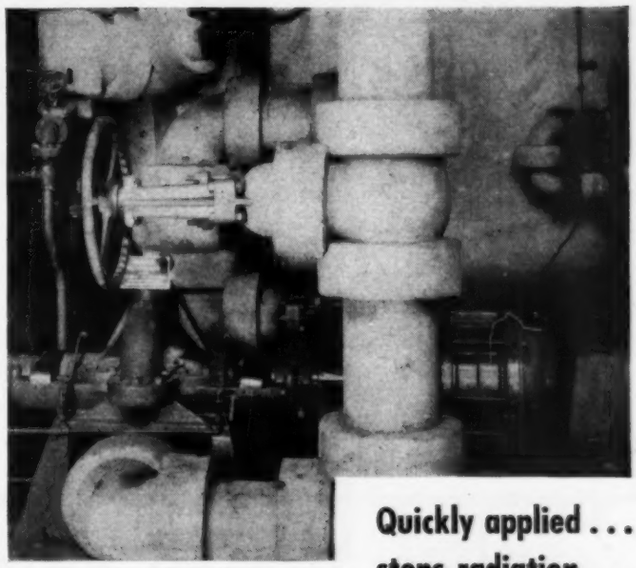

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